PROCEEDINGS OF THE BIOLOGICAL SOCIETY OF WASHINGTON
115(2):273–320. 2002.

Current diversity, historical analysis, and biotic integrity of fishes in the lower Potomac basin in the vicinity of Plummers Island, Maryland—Contribution to the natural history of Plummers Island, Maryland XXVII

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Abstract.—The Plummers Island, Maryland, area has one of the more intensively studied biotas in the world. Abundant historical data on fishes of the Potomac River and tributaries, dating from the late 1800s and vouchered by museum specimens, in combination with sampling conducted in this investigation and by other recent investigators, has facilitated a definitive historical analysis of fish diversity in the region. Extensive changes in the integrity of that fauna through both extirpation of native species and addition of non-natives are documented. Eighty-six species have been recorded from the study area. It had a moderately diverse native fish fauna of 56–61 species of which 40 maintain viable populations today. Up to 30 non-native species were naturalized in the area for a time, or repeatedly introduced, and 22 remain. Enigmatic distribution patterns in the Fall Line ecotonal area may owe to a combination of gradient profiles in tributaries and Pleistocene history. There are indications that the C & O Canal may have played a role in dispersal of lowland species through and beyond the study area. These complex distributions have implications regarding the applicability of regional indices of biotic integrity criteria to studies of these streams. Sampling protocols and indices of biotic integrity, strongly based in historic data and tailored to individual streams, were devised to provide an easily repeatable method for present and future monitoring of fish assemblages and assessing stream health in Potomac tributaries in the study area. Those indices currently indicate depressed biotic integrity in these streams and generally corroborate declines documented in the historical analysis. It is recommended that these sampling procedures be repeated at future dates to monitor trends and to provide guidance for environmental planners.

Thanks to the attention, efforts, and support of the Washington Biologists' Field Club (WBFC), the biota of the Plummers Island area, lying at the periphery of the Club's home in the District of Columbia (D. C.), is among the most intensively studied and best documented in the world. Manville (1968) recounted the Club's early history, which began in 1900, and its efforts to acquire and preserve Plummers Island and to promote studies of the biota both on the island and in the surrounding area. These efforts had yielded 350 publications on the flora and fauna of the island's vicinity by 1968 and several more have ensued to present. Among these are the 26 numbered contributions in the Biological Society of Washington's *Proceedings* and *Bulletin* to which this contribution is added.

Among the early contributions was that of McAtee & Weed (1915) providing the first list of fishes in the vicinity. McAtee

(1918) published maps and information of value in pinpointing local names used in conjunction with numerous fish collections in the U.S. National Museum of Natural History (USNM) of late 1800s and early 1900s vintage. The second work specifically treating fishes of the Plummers Island area was that of Manville (1968) who listed all vertebrates known for the vicinity. His accounts provided a synopsis which included a relatively uncritical recapitulation of McAtee & Weed's (1915) listings as well as two other early contributions to the knowledge of fishes occurring in the D. C. area (Smith & Bean 1899, Bean & Weed 1911). It also included previously unpublished collections made in tributaries in Montgomery County, Maryland, near Plummers Island by R. R. Miller, J. Simon, and J. R. Alcorn during 1944 which yielded the only glimpse of fish occurrences for a period of several decades. Other important contributions, not treated by Manville, which lend insight to the history of occurrences of fish species in the lower Potomac area, were the early compilation of Uhler & Lugger (1876) and later works of Radcliffe & Welsh (1916) and Fowler in Truitt et al. (1929). Aside from the aforementioned collections of Miller et al. in 1944, there was little effort to document the fish fauna of the lower Potomac area until the 1970s when a number of area agencies undertook studies of the Potomac and various area tributaries. A number of reports ensued over the following twenty or more years which were not published in the primary literature but are incorporated, as critically as possible, herein. Of course, some of the area has been subjected to heavy urbanization and drastic alterations over the more than a century spanned by all of the above contributions.

In 1995, the WBFC commissioned the present study. It attempts to analyze the history of occurrences over the past 125 years or more as well as document recent occurrences. It also provides a measure of the current biotic integrity of tributary fish populations at selected sites in the vicinity. These are intended to provide sound bases for future replications of these studies to facilitate relatively rigorous analyses of changes or trends in species occurrences, community compositions, and stream health in the area.

Study Area

Both McAtee & Weed (1915) and Manville (1968) delineated the study area for fishes of the Plummers Island vicinity more broadly than investigators of other floral or faunal groups. While studies of other groups had been confined to the island and the WBFC's adjacent holding near the mouth of Rock Run on the river's Maryland shore, these fish studies were expanded both up and down river with Plummers Island situated about midway within the reach (Fig. 1). They included the reach of the Potomac from Great Falls to Little Falls, the adjacent C & O Canal, and lower portions of several tributaries entering that reach. Those tributaries were Turkey, Dead, Scott, and Difficult (mouth only) runs on the Virginia versant of the river and Cabin John and Rock runs on the Maryland versant. All are located within Fairfax County, Virginia (VA) and Montgomery County, Maryland (MD). Unfortunately, despite maps delineating the previous study area (McAtee & Weed 1915 pl. I and Manville 1968 fig. 3), stated localities given for tributary collections are vague, both in the written report and with collections in USNM. It is difficult to discern how far those tributaries were ascended for surveying. This presents some problems in comparisons with present-day fish occurrences.

In the present study, the above streams were revisited but the scope was considerably expanded to include headwater reaches. It also includes several sites in the large Difficult Run system and, Bullneck Run (Fig. 1), a small Virginia tributary omitted by McAtee & Weed. Headwater stations were omitted in the case of Turkey and

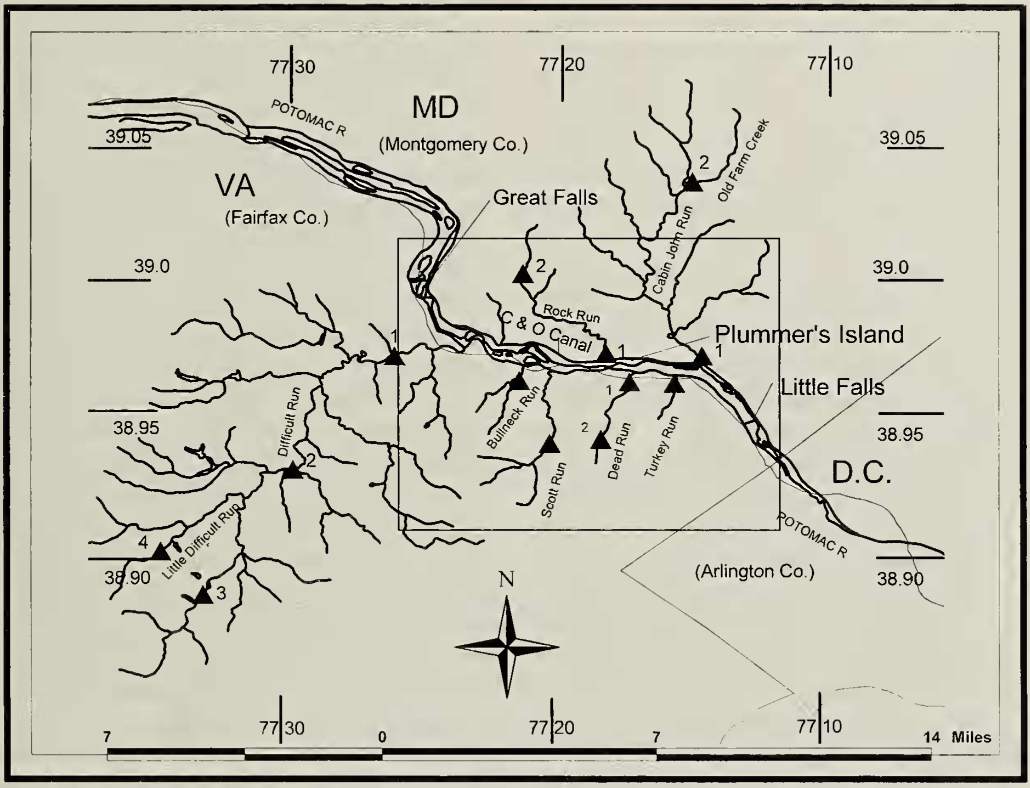

Fig. 1. Map of Plummers Island and vicinity expanded study area, Montgomery County, Maryland, and Fairfax County, Virginia. Inset delineates approximately the scope of study areas of McAtee and Weed (1915) and Manville (1968). Black triangles denote IBI sample sites for fishes in current study. Numbers denote locations on those tributaries with multiple sampling sites as described in Field Methods.

Bullneck runs because of their limited lengths and relatively homogeneous habitat throughout. The headwaters of Scott Run were not examined because of lack of accessibility due to urbanization. The C & O Canal suffered damage from flooding near the time of the survey and plans to conduct later surveys in 1996 were completely thwarted by tremendous flooding and damage that necessitated draining of the canal. It therefore was not included in the study.

The study area, which includes approximately 293 km^2 of tributary watersheds, is situated in the Fall Zone at the interface of the eastern division of the Piedmont and the Coastal Plain physiographic provinces but lies entirely just above the Coastal Plain per se. Here, the surface geology at the Piedmont's eastern margin is dominated by Devonian formations of metamorphosed sedimentary rocks, particularly shales, siltstone, schist, and gneiss, with some localized belts of intrusive Paleozoic granitic and igneous rocks (Crowley et al. 1971). Watersheds in the study area are underlain chiefly by the Wissahicken formation, composed of micaceous and chloritic schist.

In this zone, the Potomac River has cut a gorge of considerable depth, particularly on the Virginia versant where scarps and slopes may exceed 100 m vertical relief. The river consists of series of falls and tumultuous rapids with intervening reaches of deep, swift channels and some calmer backwaters. Substrates of the river consist of extensive bedrock, angulate boulders, with some reaches of gravel or silty sand. Rooted vegetation is abundant in shallow areas.

Flows over the past decade have ranged widely from extreme lows of near 28 cms to highs of 7793 cms following Hurricane Fran in 1996. In lower flow periods water clarity is generally murky as a manifestation of relatively high primary productivity. Turbidity is high during periods of increased flow (see sediment load data below). Maximum water temperatures in the expansive and exposed channel may exceed 32°C in summer. Despite warm temperatures and demands of productivity, dissolved oxygen remains high (7–15 mg/l) due to the extensive turbulence in the reach.

The salient feature of this reach is Great Falls, at the upper terminus of the study area, which descends some 27 m in little over 2 km with a 12 m plunge at one point (Stevenson, 1899). It is a formidable barrier to upstream movement of fishes and has no doubt marked the limits of migration for several anadromous species for eons. Little Falls, 14 km downstream at the lower terminus of the study area, was a much less formidable structure, with irregular cascades of 1 m or less in its natural state. In that state, it was apparently only somewhat of an impedance to some migratory species but a complete barrier to others. According to Nichols (1968), this barrier was made more formidable by the construction of a boulder diversion dam in 1831 to shunt water to the C & O Canal, though breaks ensued over the years which probably permitted fish passage. In 1949, a concrete cap of this dam was completed negating most fish passage except in times of very high flows. In 1959, Brookmont Dam, with a vertical relief of nearly 3 m, was constructed above the former structure and a fishway was constructed in an attempt to facilitate traversal of both the old and new structures by anadromous fishes. This fishway has not proven successful and a modified design is soon to be completed in hopes of reestablishing stronger runs of American Shad and Striped Bass (B. P. Yarringtion, Federal Energy Regulatory Commission, pers. comm.).

Adjacent to the Potomac, on the Maryland shore, the C & O Canal was completed between Georgetown, D.C., and Seneca, Maryland, by 1831 (Appendix III: C & O Canal Assn.). This canal, averaging 15 m in width and provided with locks, created a large conduit of slackwater habitat that circumvented and surmounted the entire Fall Zone reach of the Potomac. It remains in existence today, though it has been subjected to frequent flood damage and drainings over the years. The utility of canals as dispersal pathways has been debated (e.g., Daniels 2001). Evidence of the efficacy of the C & O in this regard is analyzed below.

Turning to tributary streams in the study reach, the distinctive feature of these streams is their precipitous descent, up to 35 m, into the gorge over the lower kilometer or so of their courses, particularly on the Virginia shore. The lower reaches (0.2–1.0 km) of all tributaries consist of high gradient rapids, small falls, and short runs and pools with substrates dominated by bedrock and boulders. The relatively short (2–3 km) Turkey and Bullneck runs (Fig. 1), small order tributaries with watersheds of only about 4.0 km^2 each, are characterized by such habitat over much of their length. Dead, Scott, and Rock runs are slightly larger (6.8,13.3,12.5 km^2) streams with much of their drainage areas lying outside the gorge. They are of relatively lower gradient over much of their courses with alternating gentle riffle and pool habitat and extensive areas of softer substrates, such as sand, gravel, silt, and detritus. These characteristics also apply to Cabin John Run (49 km^2) and much larger Difficult Run system (203 km^2).

It is not the intent of this report to delve in detail into physical/chemical water quality measurements of study area tributaries but rather to let the composition of fish communities make statements. Physical/chemical characteristics of these streams have been well studied by area agencies. However, a brief history of water quality is incumbent because of discussions of changes in species compositions and biotic integrity that will ensue. Today, basic physical/chemical characteristics of tributaries are not substantially out of the ordinary. Dissolved oxygen levels are generally good with saturation exceeding 80%; pH is near neutral, turbidity is low much of the year, and summer water temperatures generally do not exceed 23°C. However, these generalizations belie problems that have plagued most area streams following European settlement. Prior to that period, the heavily forested watersheds and underlying schistose rocks, which are low in nutrients, would generally predict cool maximum temperatures, near neutral to slightly acidic pH, and chemical profiles fostering modest productivity. The history of European settlement and subsequent development in the study area is long and significant impacts probably exceed well over two centuries. First to come was clearing of forests and agriculture resulting in erosion and siltation. Ferguson (1876) reported that numerous Maryland streams had already been decimated for many years by mid 1800s. Later, suburban development began west of the District of Columbia and began to greatly accelerate by the 1940s. However, some portions of the riparian areas bordering tributary streams in the study area were preserved as green belts and the lower reaches lie within the narrow national parklands bordering the Potomac.

Land use configurations vary among tributaries. In Maryland, 80% or more of the riparian areas of the Cabin John and Rock runs systems are narrowly to broadly forested but the vast majority of the watersheds are urbanized (Appendix III: Montgomery Co. Stream Protection Strategy). Forestation ranges widely from 3–40% among tributaries. Impervious surfaces average about 20% in these areas, promoting excessive runoff and expediting flow of non point source pollutants to streams, and lawns comprise 50–70% of watershed area constituting an extensive source of chemical pollutants and nutrient (e.g., fertilizers) loads. In Virginia, Dead and Scott runs have similar configurations while shorter Bullneck and Turkey runs lie mainly in protected forests. Headwater tributaries of the large Difficult Run system lie principally in wooded areas whereas the lower course and much of the tributaries received in its lower reaches traverse residential areas with land-use characteristics more similar to Maryland tributaries.

Water quality has suffered greatly at times over the last several decades. For instance, in 1974, water quality of Cabin John Run was rated as poor with high biochemical oxygen demand, high phosphate, and high fecal and total coliform counts based on Montgomery County Department of Environmental Protection data. In 1996, that agency's indices of biotic integrity (see Methods below) indicated marginal to sub-optimal conditions at all stations in this watershed (Appendix III: Montgomery Co. Dept. Environ. Protection) as did those from Rock Run which had registered excellent water quality in 1974, indicating declines in water quality over the past 20 years.

The mainstem Potomac River passing through the study area has endured a long history of pollution. Degradation of the Potomac first stemmed from heavy sediment loads connected with the above-mentioned extensive clearing and heavy agricultural development within its watershed in the 18th and 19th centuries. These were followed by impacts from industrial wastes, particularly downstream from the Shenandoah Valley area. This period saw the first effects of sediment and chemicals from mine drainage of the extensive coalfields of the upper Potomac watershed and the ill-treated municipal wastes of many towns (Appendix III: Alliance for Chesapeake Bay). Improved farming practices diminished erosion over the past several decades, permitting some improvement in water quality, though the combined effects of all impacts probably reached their peak in the 1950s and 1960s (Appendix III: Interstate

Commission Potomac River Basin). With the implementation of much improved sewage treatment and curtailment of other detriments, the Potomac has steadily improved in water quality since those decades, though episodic influxes of heavy silt and associated pollutants remain a problem (e.g., Ator et al. 1998). Water quality parameters associated with domestic and municipal sewerage (total phosphates, ammonia, organic nitrogen, and others) register marked improvement since 1979. Sediment transport loads through the study area vary widely from 50 tons/day through much of year to influxes of 70,000 tons/day during peak flows in the 1990s (Lizarraga et al. 1998). About one million tons annually enter the study reach; most is transported to the tidal Potomac but lower-velocity areas within the reach receive significant sedimentation. Associated with this, pesticides persist in easily detectable amounts, as do levels of mercury and polychlorinated biphenyls (e.g., Gerhart & Blomquist 1996, Zappia & Fisher 1997). Despite this, with the above history in view, water quality of the Potomac above D.C. may be the best that it has been since at least the earlier part of the 20th century.

Methods

Current and historical diversity of the study area was ascertained through compilation of fish records from historical literature and museum specimens, agency reports, and surveys conducted by the investigator in 1995. No literature or faunal survey records were uncritically accepted in the absence of voucher specimens or corroborated occurrences. Much of the voucher material from earlier surveys of the study area is deposited in the U.S. National Museum of Natural History (USNM) while vouchers from the 1995 study reside in the North Carolina State Museum of Natural Sciences (NCSM 26953-27020). Additional museum abbreviations follow Leviton et al. (1985) except USMF is Frostburg State University, Frostburg, Maryland.

Field methods.—Study sites in tributaries in the study area were rigorously sampled to facilitate both the overall faunal analysis and analyses of biotic integrity (below). No attempt was made to quantitatively sample the main Potomac River because the boundless nature and ruggedness of the habitat negated possibilities of effective sampling in a confined area with the available gear. However, considerable effort was expended in sampling the river about Plummers Island with 3- and 8-m seines in an attempt to qualitatively investigate fish occurrences. I relied primarily on agency surveys using more effective gear for fish occurrence data in the main river.

Where appropriate and practical, sample sites were selected in both headwater and lower reach portions of tributary streams in order to accommodate differences in species composition related to longitudinal zonation, stream order, or intrabasin variation in water quality. The seven tributary stream systems in the study area were sampled at a total of 13 sites (Fig. 1) in 1995. Coordinates (derived from 3-D TopoQuads software, 1999, DeLorme Corporation, Yarmouth, Maine, U.S.A.) are given to facilitate precise relocation of sites. In Fairfax Co., VA, locales and dates were: Turkey Run just above George Washington Parkway (38°57.7680'N, 77°09.4740'W) 6 Jun 1995; Dead Run (2 sites), 1) just above George Washington Parkway (38°57.8040'N, 77°10.4400'W) 7 Jun 1995 and, 2) 100 m below Churchhill Rd. (38°56.7252'N, 77°10.9798'W) 6 Jun 1995; Scott Run 20 m above Hy. I-495 off Old Dominion Rd. 38°56.7636'N, 77°12.1050'W) 6 Jun 1995; Bullneck Run 0.7 km above mouth (38°57.9300'N, 77°12.8760'W) 20 Jun 1995; Difficult Run system (4 sites), 1) Difficult Run at Leigh Mill Rd. immediately downstream of bridge (38°58.2930'N, 77°16.1748'W) 7 Jun 1995, 2) 100 m above Hunters Mill Rd. (38°55.8060'N, 77°18.3432'W) 30 Jun 1995, 3) off Miller

Heights Rd. 1.2 km below Fox Mill Rd. crossing (38°53.1462'N, 77°19.8642'W) 25 Jun 1995, and 4) Little Difficult Run 100 m above Stuarts Mill Rd. (38°54.5340'N, 77°21.1764'W) 30 Jun 1995. In Montgomery Co., MD, these were: Rock Run (2 sites), 1) 100 m above MacArthur Blvd. (38°58.6050'N, 77°11.007'W) 30 Aug 1995, and 2) immediately above Oaklyn Rd. (39°00.2244'N, 77°12.8424'W) 7 Jun 1995; Cabin John Run system (2 sites), 1) Cabin John Run 150 m above MacArthur Blvd (38°58.4142'N, 77°08.9664'W) 20 Jun 1995 and 2) Old Farm Cr. 150 m above Cabin John Run (39°02.0256'N, 77°09.1554'W) 30 Aug 1995.

At each sampling site, a 30 m reach of stream was selected. These generally included two riffle/pool segments, except for the large lower Cabin John and Difficult Run sites which contained one each, and all sites featured ample representation of all basic habitat types—riffle, run, pool, and undercut banks. Reaches were sealed off at both ends with seines and sampled by repeated passes of backpack electroshocker, dipnets, and seines with an aim at total removal of all fish from the area in order to gain the most thorough qualitative results. Fish were held alive in numerous buckets while sampling continued until no further fish could be located. At completion of sampling, fish were identified, measured, divided into size groups to facilitate age structure analysis, and counted. Most fish were released but vouchers of all species were retained.

Indices of biotic integrity.—To facilitate future comparative studies of fishes in the Plummers Island area, indices of biotic integrity, or the IBI (Karr 1981, Fausch et al. 1984, Karr et al. 1986, Leonard & Orth 1986, Angermeier & Schlosser 1987, Plafkin et al. 1989, and others), were derived from the data afforded by the above sampling. This application provides a repeatable method by which future investigators can revisit the 1995 study sites and approximately replicate the sampling and data treatment of the initial study. In general, these indices are derived by application of metrics, which, in most studies, are related to species composition, trophic composition, and fish condition. Other pertinent ecological or life history information may be considered in analyzing the community composition at a given site. Observed values are compared to values expected in the absence of degradation. Expected values may be based on knowledge of former fish distribution and regional biogeographic considerations as well as drainage basin size. High scores indicate greater biotic integrity, i.e., attributes similar to that of least disturbed assemblages (Smogor & Angermeier 1999b).

Several IBI investigations from the Maryland-Virginia region, including some aimed at laying foundations for future regional work (e.g., Scott & Hall 1997, Roth et al. 1998, Smogor & Angermeier 1999a, 1999b) were consulted for applicable metrics, feasible predictors of species richness, and rating criteria. Several metrics were adapted for use in the IBI, others were rejected for reasons given in the IBI Analyses section, and applicable species richness curves were not available.

In deference to broad-based expectations of species richness, the extensive record of historical collections in Plummers Island area streams (Appendix I) served as the bases of expected species occurrences, richness, and other expectations against which the results of 1995 sampling were compared (Appendix II). In most cases, actual former occurrences in a particular stream form the basis. In some cases, expected occurrence was based on former occurrence in immediately adjacent streams with similar physical habitat characteristics and accessibility for immigration to the stream in question. Thus, the rating criteria for these metrics are individually tailored for each sampling site to facilitate the best correlation of results for this and future comparisons.

IBI metrics selected (Appendix II) that

derive from trophic or reproductive guild criteria, as well as occurrences of various classes of species (e.g., native, nonnative, tolerant, intolerant), were applied as proportions of the above expectations in order to obtain scorable percentages. Tolerance ratings are derived from several sources (Scott & Hall 1997, Barbour et al. 1999, Smogor & Angermeier 1999a, Appendix III: North Carolina Division of Water Quality) and reflect a consensus. Only species rated as fully tolerant were regarded as such in calculations of the proportion of tolerant species to total species present; species of medium tolerance and intolerant species were combined as having reduced tolerance. Though some studies ignore presence of young-of-year in compilations of IBI samples, this age class was included in this study for reasons stated in the Analyses. Assignment of species to guilds, e.g., trophic, reproductive, was based on those same sources as well as biological information found in Jenkins & Burkhead (1993), Etnier & Starnes (1993) and other references as well as the author's personal knowledge. Assignment to the Substrate Manipulator Spawner guild was broadly interpreted to include all spawning associates (e.g., *Notropis rubellus*) of nest-building cyprinid species, such as *Nocomis micropogon,* because these species very likely indirectly benefit from substrate manipulation by the nest builders through their choice of spawning sites. Implications of another metric employed, percentage of species with multiple age classes present, a manifestation of ongoing reproductive success and recruitment, are self-explanatory.

In Appendix II, scoring of the ten IBI metrics ranges 1–5 thus yielding a possible score of 50 for each sample site. Scoring is based on the percentage of occurrence of a given attribute. The eight metrics positively correlated with increased biotic integrity (e.g., percent expected native species present) are scored as follows: 0% = 0, 1–20% = 1, 21–40% = 2, 41–60% = 3, 61–80% = 4, 81–100% = 5. Two negatively correlated metrics (i.e., percent expected nonnative species present and percentages of tolerant species present) are scored in the reverse.

Stream health, or biotic integrity, at each sample site was arbitrarily rated (Appendix II) based on the total scores derived from the metrics as follows: 0–10 = very poor, 11–20 = poor, 21–30 = fair, 31–40 = good, 41–50 = excellent.

Historical Analysis and Current Surveys

McAtee & Weed (1915) listed 55 fish species in 12 families in the Plummers Island vicinity and Manville (1944) recorded slightly more (57 species in 14 families); these totals included native and nonnative species. The present study reveals a total of 86 species representing 21 families that have been definitely recorded, or very probably have occurred, in the Plummers Island study area (Appendix I). An analysis of their occurrences over the past 125 years or so follows. At least 56 of these species are thought to be native to the lower Potomac region with the large balance being either questionably native or definitely nonnative. Forty of the native species have persisted in one or more streams in the study area since the 19th century, though some are diminished or extirpated in streams where they formerly occurred. The other 16 native species have very unstable histories in the area. The more detailed portions of the analysis that follows are confined mainly to those species having unstable or not well-understood histories, to migratory species, and to the extensive history of nonnative introductions.

Migratory species.—Migratory fishes, including both diadromous species and those which undergo lesser migrations confined mainly to freshwater, are particularly noteworthy of discussion because of the exclusionary nature of Little Falls and Little Falls Dam downstream of Plummers Island and will lead the analysis. The Sea Lamprey, *Petromyzon marinus,* is a parasitic anadromous species, entering the Potomac and tributaries to spawn in spring, penetrating just to the Plummers Island reach (Jenkins & Burkhead 1993) with young stages (ammocoetes) remaining in fresh water for several years. It was last reported in the area from Little Falls Dam fish passage in 1960 and Cabin John Run in 1944 (Appendix I). Few spawning adults have probably been able to surmount Little Falls Dam since about 1949, but there are relatively recent occurrences in Potomac tributaries a few miles downstream such as Rock Creek (in 1989, J. M. Mudre, Federal Energy Regulatory Commission, pers. comm.), and tributaries of Anacostia River tributaries and the Piscataway Creek system (Appendix III: Dietemann 1977, Cummins 1989). The secretive nature of ammocoetes and ephemeral occurrences of adults may limit knowledge of their distribution.

The two anadromous Atlantic coastal sturgeon species, the Atlantic (*Acipenser oxyrinchus*) and Shortnose (*Acipenser brevirostrum*) sturgeons, have not been definitely recorded from the Washington, D. C. area since 1899 and 1876, respectively (Appendix I). These large, primitive fishes formerly penetrated well up the Potomac estuary to spawn in spring (Lippson et al. 1981, Jenkins & Burkhead 1993). The former was considered common in earlier times (Uhler & Lugger 1876) but was already considered rare by the late 1800s (Smith & Bean 1899). However, these species probably seldom penetrated to Little Falls which, even prior to construction of the dam, they reportedly did not traverse (McAtee & Weed 1915). The single record (USNM 16730 [USNM 26273, as given in Jenkins & Burkhead 1993, is in error]) of Shortnose Sturgeon is from the vicinity of Little Falls. While Jenkins & Burkhead (1993) considered sturgeon stocks greatly diminished, rare wild Shortnose Sturgeon occurrences, as well as both wild and hatchery reared Atlantic Sturgeon, have been recently reported (Appendix III: Eyler et al. 2000, Skjeveland et al. 2000) in portions of Chesapeake Bay, including the lower Potomac estuary, in 1996–1998. Rare future occurrences near the Plummers Island reach might be anticipated.

Four anadromous shad and herring species historically entered the upper Potomac estuary to spawn in spring. Stevenson (1897) and McAtee & Weed (1915) stated that American Shad (*Alosa sapidissima*) traversed the study area to the barrier at Great Falls but only small numbers apparently entered that reach since completion of the new dam at Little Falls in 1959 (Nichols 1968, Leathery 1999) The ascent of Alewife (*A. pseudoharengus*) and Blueback Herring (*A. aestivalis*) generally halted at Little Falls even prior to damming. The latter two species remain abundant in early and late spring, respectively, in the river reach below Little Falls, as well as area tributaries, but American Shad are now uncommon (pers. obsv. & Appendix III: Tilak & Siemien 1993, 1994). Hickory Shad (*Alosa mediocris*) were stated to be common in the D.C. area at the turn of the century (Smith & Bean 1899) but were not listed for the Plummers Island area by McAtee & Weed (1915). Though spawning migrations above Alexandria, Virginia, were questioned by Lippson et al. (1981) and the Hickory Shad's overall distribution (e.g., Jenkins & Burkhead 1993) suggests it penetrates little above tidal waters, and, though early 1990s records (Appendix III: Tilak and Siemien 1992, 1993, 1994) indicated this shad to be rare, the late 1990s reportedly brought strong runs, penetrating to at least Chain Bridge near the study reach (J. D. Cummins, Interstate Commission Potomac Living Resources, in litt.). A fifth clupeid species, the Gizzard Shad (*Dorosoma cepedianum*) is an abundant resident of the lower Potomac River and estuary and a net migration to the Fall Line area occurs in spring (Lippson et al. 1981). Records from upstream of Great Falls (e.g., Jenkins & Burkhead 1993) and from within the study reach below Great Falls may stem from migrants which circumvented that barrier via the C & O Canal where it was long ago reported by McAtee & Weed (1915).

The Longnose Gar (*Lepisosteus osseus*), north of the James River basin, has a primarily Coastal Plain distribution (e.g., Jenkins & Burkhead 1993) and shows net migration tendencies similar to Gizzard Shad. Older records (Appendix I) occur downstream of the study area and this gar recently reported in freshwater tidal reaches (e.g., Killgore et al. 1989) but, while it readily penetrates upland rivers in other portions of its range (e.g., Wiley 1980, Etnier & Starnes 1993), it has not been recorded from within or above the study reach in the Potomac. An hypothesis is posed that the Potomac gar population may be product of a relatively recent northward postglacial dispersal which was halted at Little Falls. Currently, occasional entrainments into the C & O Canal might be expected.

The anadromous and highly sought-after Striped Bass, *Morone saxatilis,* ascended to Great Falls, as did the semi-anadromous White Perch, *Morone americana,* which migrates only a short distance to spawn (McAtee & Weed 1915, Lippson et al. 1981). Striped Bass still occur regularly in the reach below Little Falls (Appendix III: Tilak & Siemien 1992, 1993, 1994) but have not been recorded above. White Perch spawn in abundance (pers. obsv.) between Chain Bridge and Little Falls but do not surmount the dam and the Fall Line is generally considered the natural upstream limit with upstream records probably attributable to passage through the C & O Canal (Mansueti 1961). The semi-anadromous Yellow Perch, *Perca flavescens,* less restricted to the Coastal Plain than the previous species, was common in the Potomac River and C & O Canal at the turn of the century and remains so today below Little Falls (Appendix III: Tilak & Siemien 1992, 1993, 1994) but is apparently rare between Little and Great falls based on lack of records in several reports examined.

The remaining migratory species, the catadromous American Eel, *Anguilla rostrata,* which spends its juvenile and adult life in streams or estuarine waters but spawns at sea, was abundant historically and remains common in the Potomac and Plummers Island area streams (Appendix I). Most specimens collected in this study were subbreeding adults in the 30–70 cm TL range but the presence of smaller individuals down to 15 cm suggests that some eels readily surmount Little Falls Dam at a relatively young age.

Three primarily estuarine species, the Bay Anchovy, *Anchoa mitchilli,* Inland Silverside, *Menidia beryllina,* and Atlantic Needlefish, *Strongylura marina,* are known (Appendix I) to move into the freshwaters of the Potomac to the lower portion of the high gradient reach below Little Falls. Presumably these species find their limits at the downstream terminus of the study area.

Native Coastal Plain species.—Eleven non-migratory fish species resident to the lower Potomac are or were generally confined to the Coastal Plain at that latitude (Lee et al. 1980, Jenkins & Burkhead 1993). Most of these have the upstream limits of their distributions in the vicinity of the study area. The Bowfin, *Amia calva,* ranges northward in Chesapeake Bay tributaries to Pennsylvania (Lee et al. 1981) but records are rare north of the York River drainage in Virginia. In the Plummers Island reach it is represented by a single record plotted in Jenkins & Burkhead (1993), an adult taken by a fisherman below Great Falls in 1979 (R. E. Jenkins, Roanoke College,). This record, in addition to several others from above Great Falls may stem from local introductions in portions of the Potomac sometime prior to 1978 (Jenkins & Burkhead 1993) or, alternatively, may stem from upstream migrants of native stock via the C & O Canal. However the extreme paucity of records in the lowland Potomac in the D.C. area and downstream (one from Charles Co., Maryland, reported in Truitt et al. 1929) may favor the former explanation.

The primarily Coastal Plain-distributed Bridled Shiner, *Notropis bifrenatus,* has disappeared from much of its range in North Carolina and Virginia (Jenkins & Burkhead 1993) and appears to be declining rapidly in more northerly portions of its range as well (R. E. Jenkins & K. E. Hartel, pers. comm.). Though not reported by McAtee & Weed (1915), it formerly occurred in the lower Potomac drainage based on several vouchered records from the vicinity of D.C. and downstream from 1935 and earlier years (e.g., Jenkins & Zorach 1970). Records in the Plummers Island vicinity include the main river at Little Falls and Chain Bridge (USNM 64364, 75982, 93894) collected between 1908 and 1911. A putative 1901 record from Difficult Run (USNM 85585) and a 1912 record from Cabin John Run (USNM 84758) are here reidentified as *Cyprinella analostana* and *Notropis procne,* respectively. There are no confirmed records from the Potomac drainage since 1935. Records in recent survey reports from nearby areas (Ernst et al. 1995, Appendix III: Cummins 1989) are based on other species (J. D. Cummins, R. E. Jenkins, pers. comm.).

Two records of the White Catfish, *Ameiurus catus,* including the 1978 record in Appendix I, are from the reach between Plummers Island and Great Falls. There are no records of this primarily Coastal Plain-distributed species from the C & O Canal and it is speculative whether the canal has served as a conduit for that species or that it penetrated the high-gradient reach. In more southerly Atlantic Slope drainages (e.g., James, Roanoke, and southward), it penetrates upland provinces to the Blue Ridge (Menhinick 1990, Jenkins & Burkhead 1993). Current distribution, relative to more southerly basins, might be explained by postglacial dispersal phenomena similar to that of Longnose Gar (above).

The Eastern Mudminnow, *Umbra pygmaea,* maintains populations in sluggish lower Potomac habitats up to the D.C. area, including the Anacostia River system (Jenkins & Burkhead 1993, Howden & Mansueti 1951, Appendix III: Cummins 1989) and one dated record is from the river or canal in 1912 near Chain Bridge (USNM 78166). Only one (unvouchered) has been reported from the Plummers Island study area proper, in Wolftrap Creek, tributary to Difficult Run (Appendix III: Fairfax Co. Stream Protection Strategy). However, upstream of the area, a population was documented in the Seneca Creek system in Montgomery County, Maryland, which enters the Potomac 12 km above Great Falls, as recently as 1974 (Appendix III: Dietemann 1974) and additional records are from tributaries to the Canal in the nearby Poolesville area in 1997 (USMF 9725, 9728, 9730, 9731). These populations would appear to stem from the C & O Canal which has provided a corridor of artificial lowland habitat surmounting the Fall Line.

Three additional lowland species might be expected in the slacker portions of the study area (e.g., C & O Canal or other) but only one has been definitely recorded. The Tadpole Madtom, *Noturus gyrinus,* and Bluespotted Sunfish, *Enneacanthus gloriosus,* were recorded in the D. C. area early in the century up until 1926 (Appendix I). The Bluespotted Sunfish was reported to be abundant in the Potomac in the 1800s (Uhler & Lugger 1876). Recent rare occurrences are recorded nearby from the Potomac River (*E. gloriosus* by Killgore et al. 1989) and Anacostia systems (both species, Appendix III: Cummins 1989) downstream of the study area. Denizens of slack waters and abundant cover, such as vegetation, undercut banks, and debris should have fared well in the C & O Canal if entrance was gained. However the spotty collecting history of the Canal has yielded no records and frequent drainings might have thwarted frequent colonization. The Eastern Mosquitofish, *Gambusia holbrookii,* is generally thought to be native to the Coastal Plain and lower Piedmont northward to Delaware (Jenkins & Burkhead 1993). Those authors mapped several records from Potomac tributaries in Virginia south of D. C. but, in the study area, there is but one recent unvouchered report, from Dead Run in 1999 (Appendix I). Additional records, in Maryland above the study area (USMF 9720, 9744, 9723 and five others), indicate this species has probably traversed the study area via the C & O Canal.

While the logperches, darter species of the *Percina caprodes* group (i.e., subgenus *Percina*), are primarily of upland distribution, the logperch formerly inhabiting the Potomac occurred on the Coastal Plain. It reached its southern range limits in Atlantic coastal drainages in the lower Potomac and Susquehanna rivers (Thompson 1980) and was recorded in the lower Potomac in the late 1800s and early 1900s to near the Fall Line (Uhler & Lugger 1876, Smith & Bean 1899; USNM 68171, 70715 & six others) and at Chain Bridge below Little Falls in 1930 (USNM 89530). Lee et al. (1981), who considered the species possibly introduced along with game fishes, indicated last occurrence was possibly in 1938 (source of record not given). The possibility of the extremely early introduction of Walleye into the Susquehanna and perhaps Potomac drainages (see below) might further fuel speculation about logperches being introduced along with kindred percids. However, Jenkins & Burkhead (1993) opined that the extremely early records (e.g., 1855) of logperches in the Potomac diminish this possibility and furthermore (R. E. Jenkins per comm.) may be taxonomically distinct.

Species of upland or general distribution.—A majority of fish species in the Plummers Island area have either ecological requirements associated with upland provinces, occurring mainly above the Fall Line, or are generally distributed both above and below that physiographic demarcation. Some are denizens of larger streams and are thus confined mainly to the Potomac River.

The Pearl Dace, *Margariscus margarita,* though overlooked by McAtee & Weed (1915), was listed for the vicinity without specific locales by Smith & Bean (1899) and is documented from Cabin John Run based on a single specimen (USNM 64604, identification confirmed) collected by Weed himself and W. W. Wallis in 1909. Primarily a boreal species, it reaches the southern extreme of its range in the Potomac basin where it is very localized in a few cool, spring-fed habitats (Lee & Gilbert 1980, Jenkins & Burkhead 1993); it has probably been extirpated from many others, including in the study area. Nearest extant populations in the Potomac basin are in isolated portions of tributaries well upstream (e.g., Conocheague Creek system, Washington Co., MD) of the study area.

The Trout-perch, *Percopsis omiscomaycus,* a secretive denizen of pools and undercut banks, was sporadically distributed through much of eastern North America southward to the Potomac Basin (Gilbert & Lee, 1980) and formerly inhabited the lower Potomac (Uhler & Lugger 1876). It occurred in the C & O Canal upstream to at least the Seneca Creek area of Montgomery County, MD, into early 1900s (McAtee & Weed 1915, Radcliffe & Welsh 1916; vouchered by USNM 3373, 23387, 62523, 67518 [Plummers I.], and 107313) but is now considered extirpated (Jenkins & Burkhead 1993). The latter collection, taken near Seneca in 1911, is the last substantiated occurrence.

In addition to *Percina caprodes* discussed above, one or two other members of the darter genus *Percina* may also be extirpated from the area. The Shield Darter, *Percina peltata,* was recorded from the Potomac River below Great Falls in 1976 (Appendix III: Dietemann & Sanderson 1976), which may lend credence to the Smith & Bean (1899) record from the Chain Bridge area not accepted by Jenkins & Burkhead (1993). However, no voucher exists and the specimen in question may have represented either *P. peltata* or the very similar Stripeback Darter, *Percina notagramma.* Both species are recorded from both upstream and downstream of the study area in tributaries of the Potomac in Virgina, Maryland

and D.C.. Closest records to the study area are from Rock Creek in D.C. in 1897 (USNM 106895) and Montgomery Co., Maryland in 1944 (USNM 131758); these are confirmed as *P. peltata.* There are no occurrences of this darter in recent collections from that system (M. Haddaway, Montgomery Co. Dept. Environ. Protection., pers. comm.). It persists well upstream of the study area in the main Potomac River (1998 data, P. F. Kazyak Maryland Dept. Nat. Resources, pers. comm.).

Deserving of a note on taxonomic status, two nominal forms of the darter subgenus *Boleosoma* occur in the lower Potomac area, *Etheostoma olmstedi* Storer 1842 and *E. atromaculatum* (Girard 1859). In a study of these two taxa, Yarrington (1994) accorded subspecies status to *atromaculatum,* as had Cole 1967, and found that it was restricted to tidal portions of the Potomac and tributaries. Therefore the single taxon, *E. o. olmstedi,* occurs in the Plummers Island area which lies above tidal waters.

The distributional status of several additional species in the study area is somewhat uncertain. These are species that still maintain viable populations peripheral to the Plummers Island area and are confirmed to have formerly occurred within it or very probably did so. The Comely Shiner, *Notropis amoenus,* is an inhabitant of mid-sized to larger streams of the middle Atlantic Slope; it enters smaller streams in more northerly portions of its range (Snelson 1968). McAtee & Weed (1915) recorded this shiner from the Potomac and several tributaries, though several were apparently confounded with *Notropis rubellus* (Appendix I), especially any taken from smaller tributaries any distance above the mouth, and further confused with *Notropis photogenis,* the Silver Shiner, which is not native to Atlantic Slope drainages. Snelson (1968) did not examine several collections pertinent to clarification of the distribution of *N. amoenus* in the study area. However several lots in USNM (64408, 64410, 67530, 72960, 73352, 73398, 84700, 202173) are here confirmed to document the existence of this shiner in several of the study area tributaries as well as the main river and C & O Canal in the early 1900s (latest 1921). There are no recent records of *N. amoenus* from the area, though it remained moderately common in collections from the Potomac in reaches not far above Great Falls in the late 1970s (Appendix III: Davis & Enamait 1982). Comely Shiners are often few or absent in collections made in habitats where they are known to maintain populations (pers. obsv. and Jenkins & Burkhead 1993). This characteristic considered in light of the lack of repeated thorough sampling in the mainstem Potomac render it difficult to conclude whether the Comely Shiner is extirpated from the lower Potomac or whether more aggressive sampling would yield fickle occurrences.

A second cyprinid, the Fallfish, *Semotilus corporalis,* a large predatory species occasionally reported in surveys of Potomac tributaries up- and downstream of the study area (e.g., Howden & Mansueti 1951; Appendix III: Dietemann 1974, Cummins 1989, Yarrington 1990, Kelso et al. 1991), is known recently in the area only from very small numbers of specimens collected in the main river and Cabin John Run in 1996 (Leathery 1999 & Appendix III: Montgomery Co. Dept. Environ. Protection). There is a single unvouchered report (Appendix III: Fairfax Co. Stream Protection Strategy) from the Difficult Run system (South Fork) where it is otherwise unknown despite numerous surveys over the years. Its presence would be expected in that system based on the large creek habitat and proximate records (1976) from the Nichol Run system (Appendix III: Yarrington 1990) just above Great Falls. Most records peripheral to the study area are from the 1970s or earlier and this species may be in general decline and on the verge of extirpation from the Plummers Island area.

McAtee & Weed (1915) listed *Erimyzon oblongus,* the Creek Chubsucker, as uncommon in the Potomac and C & O Canal and there is a record which they overlooked (USNM 74805, not seen) from Rock Run near Plummers Island from 1913. No other records exist for the study area, though, like the Fallfish, it might be expected in such tributaries as Difficult Run based on physical habitat and up- and downstream occurrences in the Potomac basin. Though several viable populations exist in tributaries peripheral to the study area (e.g., Watts Br., Montgomery Co., MD, Appendix III: Montgomery Co. Dept. Environ. Protection), the Creek Chubsucker may verge on extirpation from the Plummers Island vicinity. The Chain Pickerel, *Esox niger,* was reported (not vouchered) as occasional in the C & O Canal by McAtee & Weed (1915) and as abundant in the Potomac River near Washington by Smith & Bean (1899). No recent records are known from the study area or the tidal Potomac downstream, though this weedy reach of the river would seem ideal habitat. It remains in small tributaries of the Anacostia system in Prince Georges County, Maryland (Appendix III: Cummins 1989). Smith & Bean (1899) also reported the Grass Pickerel, *Esox americanus,* as abundant in side channels and grassy tributaries in and opposite D. C.; its presence in the C & O Canal would have been expected begging the question of possible occurrences among the unvouchered, and easily confused, *E. niger* reports of McAtee & Weed. While *E. americanus* surmounts the Fall Line in the Occoquan River system, tributary to the Potomac downstream of Alexandria, Jenkins & Burkhead (1993) did not plot this species above Alexandria (where it currently maintains populations in Dogue Creek, Appendix III: Yarrington 1990) in the Potomac of Virginia and records in Maryland tributaries are restricted to well below the Fall Line (Lee et al. 1981).

Based on examination of USNM and recent field collections, two sculpin species, the recently described (Kinziger et al. 2000) Blue Ridge Sculpin, *Cottus caeruleomentum* (formerly referred to in area literature as Mottled Sculpin, *Cottus bairdii*), and Potomac Sculpin, *Cottus girardi,* have occurred in the Fall Line area of the lower Potomac on the Montgomery County, MD, and D.C. side of the river. Oddly, there are no known occurrences of sculpins in Virginia tributaries of that area; *C. caeruleomentum,* is restricted to the Shenandoah and upstream portion of the Potomac in Virginia and *C. girardi* is restricted to the Goose Creek system of the upper Piedmont (Loudon Co.) and Ridge and Valley tributaries (Jenkins & Burkhead 1993). A third sculpin species, *Cottus cf. cognatus,* "Checkered Sculpin", is isolated in several cold spring-fed streams of the Potomac but is known to occur no closer to the study area than the Monocacy system (Frederick Co., MD). McAtee & Weed (1915) did not report sculpins from the study area but Smith & Bean (1899) reported sculpins from "years ago" in a Virginia tributary above Great Falls (distance not specified) and Rock Creek in D.C. (as "*Cottus meridionalis*" and "*Uranidea gracilis,*" respectively). Later, R. R. Miller and party collected 38 in the Cabin John Run (Booze Creek and Bulls Run) system identified as *Cottus bairdii* (Manville 1968) but these (USNM 131701, 131736) are here reidentified as the later described (Robins 1961) *C. girardi.* Miller and subsequent investigators also collected specimens (USNM 131736, 241946, 241948) in the 1940s identified as *C. bairdii* from the adjacent Rock Creek system in Montgomery County; these, too, are redetermined as *C. girardi.* Both this species and *C. caeruleomentum* (as *bairdii*) were reported from Rock Creek in 1996 (Appendix III: Montgomery Co. Dept. Environ. Protection). Closely above the study area, in Watts Branch, both specimens collected by Miller et al. in 1944 (USNM 131819) and by the author in 1997 (NCSM 26955, 26956) revealed that *C. caeruleomentum* and *C. girardi* are syntopic in that system. Potomac Sculpins are reported to persist in small numbers (Appendix III: Montgomery Co. Dept. Environ. Protection) in some reaches of the Cabin John system but they were not taken at survey sites in this study, nor did targeted efforts at Miller's 1944 localities reveal their presence, and their status is considered very marginal. If unvouchered reports of Blue Ridge Sculpins from Rock Creek are correct, then that species' distribution brackets the study area and may be indicative of extirpation. In the mainstem Potomac, sculpin records (*C. girardi*) are rare and stem from about 50 km upstream of the study area in the vicinity of the Monocacy River confluence (R. E. Jenkins per comm.).

Nonnative species.—The history of introductions of nonnative species to the study area is copious and therefore the required analysis is moderately extensive. The proximity of the study area, and of the lower Potomac River in general, to the nation's capital, where the historic U.S. Fish Commission and its various successors have long been headquartered, has doubtless made it subject to experimental fish introductions that surpass many regions of the country. The conventions of the Commission were to introduce any fishes from other basins, or even other continents, which might have conceivable benefits to humankind. Attempting to showcase these efforts near the seat of power probably had considerable political intent. The Commission maintained demonstration ponds in D.C. along the shores of the Potomac. These were the source of intended introductions as well as many accidental escapes during flooding. Too, the early fisheries agencies of Maryland and Virginia assaulted the Potomac's waters with attempted introductions. For instance, in 1874–1877 alone, the Maryland Fisheries Commission attempted to establish Rainbow Trout, one or more species of Pacific salmon, landlocked Atlantic Salmon, Lake Trout, Rainbow Smelt, and the Eurasian cyprinids, Common Carp, Goldfish, and Tench in the area (Ferguson 1876, 1877). Christmas et al. (1998) note attempts to establish 57 species in the Potomac Basin over the past century and half. In the study area, a history of introductions, dating to at least 1854, brought a possible total of 29 nonnative species to the area's waters which remained established for at least a time (Appendix I) and several others which did not. Five of these were Eurasian species of which three remain established today. Between nine and 24 are North American species which certainly or possibly were introduced from basins extralimital to the Potomac.

Several Eurasian cyprinid species were introduced to the D.C. area in the 1800s. The Common Carp, *Cyprinus carpio,* whose transfer and culture in Eurasia date to 2000 or more years ago, was introduced to North America by at least the 1870s, and possibly as early as 1831 (Lever 1996), and was brought to D.C. in 1878 (Baird 1879). It was very well established in the Potomac River and C & O Canal by the late 1800s (e.g., Smith & Bean 1899) and remains common in larger habitats today. The Goldfish, *Carassius auratus,* a popular bait and aquarium fish, had an even earlier history of introductions to North America dating to perhaps the 1680s (DeKay 1842, Courtenay et al. 1984, Fuller et al. 1999) and was already established in the Potomac in the 1870s (Uhler & Lugger 1876). There remains confusion concerning the taxonomic status of various populations of Goldfish introduced into American waters with regard to the Crucian Carp, *C. carassius.* Further, *C. auratus* is regarded as a tetraploid derivative of *C. carassius* (e.g., Buth 1984) and the similar forms have probably not been well sorted out in introduced populations. Goldfish are far less common than the Common Carp but recur via repeated bait and aquarium released or escapes from established pond populations. The Ide, *Leuciscus idus,* and the Tench, *Tinca tinca,* are two additional Eurasian cyprinids, brought to the D.C. area by the U.S Fish Commission, which may have been established in the Potomac River (and probably C & O Canal) for a time in the late 1800s (Smith & Bean 1899). Neither species persists today. Christmas et al. (1998) note unintentional introductions of Grass Carp, *Ctenopharyngodon idella,* a very large cyprinid (to 45 kg) native to the Amur basin of China, often stocked for weed control in area waters. Occasional specimens should be expected in the study area but none were present in surveys considered in this report.

Besides cyprinids, the only other non-North American species known to be successfully introduced to the study area is the popular Brown Trout, *Salmo trutta,* which first arrived in North America from Germany in 1882–1883 (Courtenay 1984, Lever 1996). They had arrived in the Virginia area for propagation by 1885 (McDonald 1886, Smiley 1889) and were stocked in an unspecified Potomac tributary in 1893 (Jenkins & Burkhead 1993). Brown Trout do not often reproduce successfully in nonnative habitats but are repeatedly stocked as hatchery progeny. However a small, isolated, reproducing population persisted in Little Difficult Run in the study area in the 1980s (Lovich 1984; Appendix III: Yarrington 1990). Whether it stemmed from the 1893 or a similar vintage stocking is debatable. First documented stockings for the Difficult Run system were in 1991 (Appendix III: Odenkirk 1992).

At least nine, possibly ten, North American species recorded from the study area definitely represent introductions of extralimital species: the Threadfin Shad, *Dorosoma petenense,* Fathead Minnow, *Pimephales promelas,* Channel Catfish, *Ictalurus punctatus,* Blue Catfish, *I. furcatus,* Northern Pike, *Esox lucius,* Rock Bass, *Ambloplites rupestris,* Redear Sunfish, *Lepomis microlophus,* Smallmouth Bass, *Micropterus dolomieu,* Largemouth Bass, *Micropterus salmoides,* and White Crappie, *Pomoxis annularis.* The Threadfin Shad, native to Mississippi River basin and Gulf tributaries southward to Guatemala, was first introduced to Atlantic Slope tributaries of Virginia in the 1950s as a forage species and has been reported from the Potomac below the study area (Jenkins & Burkhead 1993) and vouchers exist for 1976 (NCSM 28733, 28734). It is not reported in recent fishery surveys of the river (Appendix I) and this relatively cold-intolerant species has probably had an ephemeral existence in the lower Potomac. The Fathead Minnow, one of the most popular of bait species, is repeatedly released into the wild outside its native range in the central United States. Though often exceedingly successful in ponds, specimens reported from streams in the eastern U.S., such as the single one taken from Difficult Run in this study, rarely represent established populations. However some area streams (e.g., Moores Run of the Patapsco drainage) are known to have well established populations (P. F. Kazyak Maryland Dept. Nat. Resources, pers. comm.).

The Channel Catfish, native to Gulf Slope, Great Lakes, and Hudson Bay drainages, has a documented history of sustained populations in the lower Potomac and larger tributaries dating to 1889 (Appendix I) when it was successfully introduced (Jenkins & Burkhead 1993). Though recorded but once from tributaries in the study area, it is abundant in the main Potomac. The Blue Catfish, native to the Mississippi and other Gulf Slope drainages, may have been introduced to the D. C. area by 1905 (Bean & Weed 1911). Radcliff and Welsh (1916) reported it from the C & O Canal. Burkhead et al. (1980) cast some doubt on early records of this catfish but conceded that it might have been among the Bureau of Fisheries' holdings in ponds near the Potomac which were often sources of intentional or accidental releases. Bean & Weed's account was based on reports of H. M. Smith, then Director of the Bureau, who most would deem competent to verify identifications. The fact that some hearsay records of over 30 pounds were reported would tend to support the existence of at least some Blue Catfish in the fishery at that time, as Channel Catfish rarely approach this size in the region. The single extant voucher specimen of that era (1911, USNM 70281), originally identified as *I. furcatus,* is, in fact, *I. punc-*

tatus (my data and Burkhead et al. 1980) and later putative specimens from 1930 (USNM 85754, 284967, 284968) are also reidentified as *I. punctatus.* The veracity of 1992 records (Appendix I) is not known, as voucher specimens were not retained. However, in the late 1990s, young Blue Catfish have been reported, along with Channel Catfish, to be numerous and increasing in numbers in the Potomac a few miles downstream of the study reach (J. D. Cummins, J. Hennessey, P. F. Kazyak, pers. comm.) indicating a recent introduction that may be flourishing. A suspected source is Occoquan Reservoir where this species has been stocked in the past.

The Northern Pike, Rock Bass, Redear Sunfish, Large- and Smallmouth basses, and White Crappie are predatory species introduced for their game and culinary qualities. The Northern Pike is wide ranging in northerly waters and sparingly introduced in more southern regions, including in impoundments of the Occoquan River downstream of the study area (Jenkins & Burkhead 1993). A single unvouchered occurrence was reported from the Potomac near the study area in 1993 (Appendix III: Tilak & Siemien 1993). Future records of *Esox* should be scrutinized relative to the rare or possibly extirpated native pickerels (above). In addition, there have been peripheral introductions (Christmas et al. 1998) of Muskellunge, *Esox masquinongy,* which might give rise to occurrences. The Rock Bass, native to the Great Lakes, Hudson Bay, and Mississippi drainages, was introduced to the Potomac by the U.S. and Virginia fish commissions in 1887 and 1898 (Jenkins & Burkhead 1993) and Rock Creek in D. C. in 1894 (Smith & Bean 1899). It persists but is not abundant in the main river today and no recent tributary records are known from the Plummers Island area (Appendix I) despite seemingly good habitat in such streams as Difficult Run. The Redear Sunfish is native to the southern Atlantic Slope and Gulf coastal drainages but has been widely introduced, particularly in small impoudments. Three juvenile specimens (NCSM 26986) taken during this study from the Potomac River at Plummers Island constitute the first record of this sunfish in the basin of the Potomac proper based on the distributions depicted in Jenkins & Burkhead (1993) and Appendix III: Zyla (1996). Presence of juveniles suggests that this species is established. This species is known to have been introduced into Clopper Lake of the nearby Seneca Creek system within the past decade (P. F. Kazyak, pers. comm.).

The Largemouth Bass, *Micropterus salmoides,* is native to Great Lakes-St. Lawrence, Mississippi, Gulf and southern Atlantic slope drainages. Conflicting references (Norris 1864, Whig 1876, and Virginia Fish Commission reports) analyzed by Jenkins & Burkhead (1993) indicate it may have ranged northward to the James River basin of southern Virginia or, conversely, may have been introduced there from further south in the early 1800s. There is a record from a pre-European archaeological site in the Roanoke River basin (T. Whyte, R.E. Jenkins, pers. comm.). Similar confusion surrounds earliest Potomac occurrences with a remote possibility of early 1800s introductions. The first possibly definitive record is from 1876 (Bean & Weed 1911, based on a mold, USNM 16841, whereabouts currently unknown). However, Largemouth Bass were being translocated years prior to that date, at least in more northerly states (MacCrimmon & Robbins 1975). Uhler & Lugger (1876) gave a possible color description of this species but their and Ferguson's (1877) references to the "Black Bass, *Micropterus salmoides*" being introduced into the Potomac and C & O Canal at Cumberland, MD, in 1854 is almost certainly confounded with the introduction of Smallmouth Bass (below).

The Smallmouth Bass, native to Great Lakes and upland portions of the Mississippi River drainage, was among the first transplants to the study area. It was brought to the C & O Canal above the study area from the Ohio River basin in 1854 (Eoff 1855) and introduced widely in the Potomac in ensuing years (summarized in Jenkins & Burkhead 1993). The Potomac population was, in turn, apparently a springboard to introductions further north in the Susquehanna and Delaware drainages (e.g., Stillwell et al. 1897). The Smallmouth Bass is common in the river and larger tributaries of the study area today (Appendix I).

The White Crappie, presently common in the Potomac River (Appendix I), is probably native only to the Mississippi and other Gulf Slope drainages and the southern Great Lakes based on the lack of early Atlantic Slope records (Smith 1907, Jenkins & Burkhead 1993, Etnier & Starnes 1993). Jenkins & Burkhead (1993) did not indicate dates of its appearance in the Potomac but Smith & Bean (1899) stated that both this species and the Black Crappie, *Pomoxis nigromaculatus* (see below), were introduced to the river and canal in 1894 and both had become abundant. Uhler & Lugger (1876) listed neither species as present at that time. Earliest USNM records of White Crappie from the D. C. area are from 1896–1898 (e.g., USNM 47692, 68164).

The possibilities are less certain that the occurrences of the remaining 13 lower Potomac species to be discussed owe to introductions. Most certain among these are probably the following centrarchid species, as well as the Walleye, *Stizostedion vitreum.* Uhler & Lugger (1876) did not list the Warmouth, *Chaenobryttus gulosus,* among the Potomac fish fauna. Its native distribution on the Atlantic Slope is not well understood (e.g., Jenkins & Burkhead 1993) but is thought to have been well south of the Potomac. Smith & Bean (1899) stated that it was introduced into the Potomac by the U.S. Fish Commission in 1895 and reported it to be flourishing. Earliest vouchers (e.g., USNM 66319, 66325, 67533) are from 1910 and after. The Warmouth remains common today in the river but tributary records are thus far limited to a single occurrence in Rock Run in 1912 (McAtee & Weed 1915, USNM 73395). The Green Sunfish, *Lepomis cyanellus,* is generally regarded as native to approximately the central United States but not the Atlantic Slope (Lee et al. 1980, Etnier & Starnes 1993, Jenkins & Burkhead 1993). Though not regarded as a particularly desirable game fish because of its small size, it is often stocked accidentally along with larger, more desirable species such as Bluegill, rendering the native range difficult to discern. It's present-day extensive, but sporadic, Atlantic Slope distribution, including numerous Potomac records in the study area dating from 1911 (Appendix I), nearby D. C. in 1908 (USNM 64356 & 57), and an earlier Potomac record (1900, Jenkins & Burkhead 1993), may stem from numerous such introductions but these actions are undocumented.

The Bluegill, *Lepomis macrochirus,* may have had native range similar to the Green Sunfish, except it possibly inhabited the southern Atlantic Slope drainages northward to the Carolinas (Page and Burr 1991, Jenkins & Burkhead 1993, Etnier & Starnes 1993, Lever 1996). Thousands of local introductions dating back many years have forever blurred the original distribution of this species but the recency of first records of this easily captured fish throughout Virginia's Atlantic drainages (Jenkins & Burkhead 1993), all within the present century, strongly indicate nonnative status. Jenkins & Burkhead (1993) gave the first Potomac record of Bluegill as 1916. McAtee & Weed (1915) apparently overlooked the presence of Bluegills as they are present in Potomac collections (originally identified as *Lepomis pallidus*) dating from 1910 (USNM 66312, 67059, 84819 & others). Bean & Weed (1911), in referring to specimens identified by W. C. Kendall as "*Lepomis pallidus*", based on the written description, may have in fact pointed to the occurrence of this species from the D. C. area as early as 1900. This name was often applied to collections of *L. macrochirus* in USNM from the 1800s (pers. obsv.), though it is probably most properly a synonym of *L. auritus* (Gilbert 1998).

The present-day distribution (Bauer 1980) of the Longear Sunfish, *Lepomis megalotis,* suggests it is not native to the Atlantic Slope drainages south of the Great Lakes-St. Lawrence drainage, though it is well established in the Potomac. Jenkins & Burkhead (1993) state the first record from the drainage is from the upper Potomac in 1953 (CU 32354), and later records from the Plummers Island area date from 1975 (Difficult Run, specimen not seen) or 1984 and after (Potomac R., Appendix I). Suspicions of prior occurrence of *L. megalotis* in the lower Potomac might be raised by Bean & Weed's (1911) and McAtee & Weed's (1915) discussions of *Lepomis auritus* and "*L. solis*". Their description of opercular flaps and coloration of the former is actually somewhat reminiscent of *megalotis* or, perhaps more likely, the Bluegill, *L. macrochirus,* rather than actual *auritus* to which their description of "*solis*" best applies. It is also possible that "*solis*" was applied to *L. auritus x cyanellus* hybrids that may have been abundant in the years following introduction of *cyanellus* (to which Bean & Weed mentioned a strong resemblance in *solis*) to the Potomac. Unfortunately, available material and original labels from that era in USNM do not resolve the issue of conflicting descriptions but the fact that McAtee & Weed failed to recognize the presence of Bluegill (above), and lack of vouchered Longear Sunfish records prior to 1970s, points to the Bluegill as the confounding entity.

The Walleye, a popular game and food fish, is occasionally taken in the Potomac today. There is slight doubt as to the native status of this species in middle Atlantic Slope drainages. The lack of definite early records (e.g., Uhler & Lugger 1876 listed it vaguely as "in the mountainous regions") has led Jenkins & Burkhead (1993) to conclude that all records stem from introductions. There is an early record (1879) from the Susquehanna drainage in Maryland (USNM 22494). However it is reputed to have been introduced to that drainage as early as 1813 from Seneca Lake, New York, and was rapidly established (Stillwell et al. 1897). It is plausible that, in turn, introduction to the Potomac may have soon followed. The Walleye was stocked in the Potomac between 1901 and 1904 (Bean & Weed 1911) which may or may not mark its earliest occurrence.

Somewhat more problematic is the native status of nine additional species. The Bowfin, *Amia calva,* and the Logperch, *Percina caprodes,* whose native status have been in question by some (e.g., Lee et al. 1981), were discussed above under native species and are probably native to the study area or, at least, the Potomac River drainage. The Silverjaw Minnow, Spotfin Shiner, Bluntnose Minnow, Golden Redhorse, and Greenside Darter are all species that have distributions mainly in the Mississippi and Great Lakes basins and one or few middle Atlantic Slope drainages (e.g., Lee et al. 1980). Bean & Weed (1911) considered that the Silverjaw Minnow, *Ericymba buccata,* had probably been introduced to the upper Potomac by the U.S. Bureau of Fisheries and had dispersed downstream. Ross (1952), Jenkins et al. (1972), Hocutt et al. (1986) and Jenkins & Burkhead (1993) indicated it is probably native to the Potomac and the adjacent Rappahannock, though the latter authors concede introduction is possible. Earliest lower Potomac record is 1906 from the back channel of Plummers Island (McAtee & Weed 1915) but this record is not substantiated by specimens in USNM. Occurrence is confirmed in Turkey and Cabin John runs in the study area in 1909–1912 (USNM 64397, 66357, 73358). These early records would indicate that this relatively delicate minnow was either transported a great distance around the turn of the century and locally introduced or dispersed with uncommon rapidity from an introduction site in the upper Potomac. Either scenario seems unlikely. Though rated as somewhat tolerant (Appendix II), and common in some relatively polluted area streams today (e.g., Anacostia R. tributaries, Appendix III: Cummins 1989), this minnow shows a history of restricted occurrence in the study area that may reflect complex biogeographic patterns or partial extirpation.

Jenkins & Burkhead (1993) regarded the somewhat similarly distributed Spotfin Shiner, *Cyprinella spiloptera,* as indigenous to the Potomac, a departure from views taken on some other species with similar distributions. They deemed that occurrences prior to 1951 might have been confounded with the similar Satinfin Shiner, *Cyprinella analostana,* thus averting detection of *C. spiloptera* in the Potomac. In fact, *C. spiloptera* appear to be documented from the lower Potomac near D. C. as early as 1922 based on USNM 85953, 9 small specimens ranging up to 40 mm SL, which appear to be correctly identified. Questionable early dates denoted in Appendix I for both *Cyprinella* species refer to the possibility that partially unvouchered early reports may have been based on one or the other species but *analostana* is documented from the main Potomac in 1911–1912 (USNM 67519, 72396). Though described from the Potomac River near D. C. (Girard 1859), *C. analostana* is today much less common in the main river than *C. spiloptera,* which has a penchant for larger habitats. No *C. analostana* were taken in the Potomac River in the course of this study and those of other recent investigations are not vouchered. It is reported to remain common well upstream of the study area in the Monocacy River confluence area (P. F. Kazyak, pers. comm.). The history of occurrence of *C. spiloptera* in the Potomac prior to the 20th century is therefore vague. Perhaps the shared distribution of *C. spiloptera* between the Potomac and its sister Chesapeake drainage, the Susquehanna, lends most plausibility to native status.

The Bluntnose Minnow, *Pimephales notatus,* was recorded through much of this century from several habitats in the study area (Appendix I), and upstream of this area in the Potomac basin (e.g., USNM 62551, Israel Cr., Washington Co., Maryland, 1903). It was abundant early in the century (Bean & Weed 1911, McAtee & Weed 1915) and is pervasive and abundant in much of the Potomac drainage today (Jenkins & Burkhead 1993). However, based on a lack of very early records (e.g., Uhler & Lugger 1876) and an erratic distributional pattern, Jenkins & Burkhead regarded this minnow as probably introduced, perhaps as forage for cultured game species in the U.S. Fish Commission's ponds in D.C. in the late 1800s.

The Golden Redhorse, *Moxostoma erythrurum,* is known in the study area only from very recent records (Appendix I). Jenkins & Burkhead (1993) stated that the first records from the upper Potomac are from 1953 and, while regarding this species as native to the James and Roanoke drainages of the Atlantic Slope, hypothesized that it was introduced to the upper Potomac with subsequent rapid downstream dispersal in recent decades. While there are few cases of successful transfer and establishment of redhorses among drainage basins by humans (e.g., Fuller et al. 1999), the lack of early records in the study area of this sucker, which is quite vulnerable to capture during spring spawning runs, strongly supports this view. An equally unlikely introduction is represented by the occurrence of the Greenside Darter, *Etheostoma blennioides,* in the study area though it was considered native to the Potomac by earlier authors (e.g., Schwartz 1965, Hocutt et al. 1986). It shares a very similar chronological history to that of the Golden Redhorse with no records in the Potomac prior to the 1950s but rapid expansion through the drainage in ensuing decades (Jenkins & Burkhead 1993). However, R. L. Raesly (pers. comm.) cites occurrence of two *E. blenniodes* populations in the adjacent Susquehanna basin, where there is collateral faunal evidence of stream capture, as evidence that this darter has a long (native) history in the Potomac basin. While still not recorded from Virginia tributaries for quite some distance above the study area, it has dispersed on the Maryland versant downstream to at least Cabin John Run (this study) and was reported once from the main river in 1976 (Appendix I).

Perhaps most problematic of all is the native status in the study area of the Brook Trout, *Salvelinus fontinalis,* and the Black Crappie, *Pomoxis nigromaculatus.* The Brook Trout is native to northern regions of eastern North America and southward along the Blue Ridge to Georgia (Etnier & Starnes 1993) and certainly is native to the upper Potomac (e.g., Cope 1868). It was present in the Difficult Run system, far disjunct from the Blue Ridge, from at least 1899, and possibly well before (Smith & Bean 1899), until its last known occurrence in 1982 (Appendix III: Odenkirk 1992). Smith & Bean also speculated it might occur in other cooler streams of the area, such as upper Rock Creek, but had no substantiation. Lovich (1984) and Jenkins & Burkhead (1993) found no stocking records in Difficult Run prior to 1902 and these authors and Jenkins and Musick (1979) regarded these populations as probably native. In Maryland, Uhler & Lugger (1876) were unclear on the Brook Trout's distribution. Such phrases as "exterminated near Baltimore" and other early indications it was being extirpated by siltation across the state (Ferguson 1877) indicate it may have once enjoyed a wide native distribution on the north side of the Potomac. This possibility may lend credence to the existence of a relictual population on the river's south side in Difficult Run. But the lack of other historical populations between the Difficult Run and the Blue Ridge, coupled with the fact that Brook Trout were already being successfully cultured for reintroduction in nearby Maryland as early as the 1870s (Ferguson 1877), render that population somewhat suspect. Numerous local reintroductions of Brook Trout across Maryland have, of course, blurred any remnants of its native distributional pattern and it has occurred sporadically in Potomac tributaries adjacent to the study area in recent decades (e.g., Appendix III: Dietemann 1974). It may be extirpated from the study area.

The Black Crappie occurs today, by virtue of known introductions, far to the north of the Potomac drainage into Canada (Lee et al. 1980). As stated above, it was introduced to the D.C. area along with White Crappie as early as 1894. However, some possibility exists that this popular pan fish was native to Atlantic Slope drainages northward to at least the Potomac based on the fact that it was sold in the Baltimore markets decades before that date (Uhler & Lugger 1876). Unfortunately, no type of preservation (e.g., salted vs. fresh) was indicated by those authors which might have given some indication of distances involved. Jenkins & Burkhead (1993) concluded that Black Crappie were probably not native north of the lower James River based on the recency and sporadic nature of records north of that drainage. However a specimen (USNM 4561) reportedly from Brookeville, Maryland, near the Patuxent River north of D.C., cataloged in the 1860s, begs questioning.

Recapitulation.—Pursuant to the above discussions, 56 of the total of 86 species recorded or certainly occurring in the Plummers Island vicinity are considered unquestionably native to the area. Thus, 35% percent of fishes found in the vicinity represent possible or certain introductions of nonnative species. Of these, three species, the Bowfin, Spotfin Shiner, and Logperch, have relatively high probabilities of being native to the lower Potomac. Six (three remaining established, one repeatedly introduced) are Eurasian species and 10 are North American species whose native ranges are definitely extralimital to the Potomac. The remaining 11 species form a continuum of possibilities ranging from questionably native (e.g., Silverjaw Minnow, Spotfin Shiner, Brook Trout, Black Crappie, Greenside

Darter) to most likely introduced (e.g., Warmouth, Bluegill).

A residue of 40 of the 56, or 71%, of definitely native species has demonstrably viable populations in one or more streams of the study area (Appendix I). Nineteen of these species are largely restricted to the Potomac River by habitat preference. Several tributary species may persist in only one or few streams based on sampling for this study (e.g., *Campostoma anomalum. Cyprinella analostana, Exoglossum maxillingua, Noturus insignis, Hypentelium nigricans, Cottus girardi, Etheostoma flabellare, and E. olmstedi*). Only six (*Anguilla rostrata, Clinostomus funduloides, Rhinichthys atratulus, R. cataractae, Semotilus atromaculatus, and Catostomus commersoni*) remain relatively pervasive of most tributaries. These latter will be discussed more fully in the IBI analyses and Discussion in following pages. Among the 30 nonnative or questionably native species established or repeatedly introduced in the Plummers Island vicinity over the years, 21 are known to maintain currently viable populations, or continue to be introduced, bringing the total of all (native and nonnative) fish species known to occur in the area to at least 62.

IBI Analyses

Construction of the IBI.—Before analyzing the results of the IBI sampling, it is reiterated that the present study is somewhat of a departure from the contextual methodology of prior studies conducted in this and other regions. It differs from most in that it is limited in geographic scope. It is therefore designed to operate within that context and to be non-reliant on expectations derived from broad regional studies. Its chief aim is to provide, station-by-station, a solid basis of comparison for future investigations to monitor improvements or declines in biotic integrity of tributary fish populations at these same sites. While it provides some basis of comparison of habitat quality among streams within the study area, that is not its principal intent. Neither is it intended to be compared, in more than a general way, to results of other IBI studies in the region whose criteria derive from broad regional sampling. The strong base of historical data from the Plummers Island area demonstrates that these criteria would be flawed if applied to area stream studies, especially with regard to predictions of species richness.

While the current study's metric criteria are based on other studies, it differs substantially from those studies in that rating criteria for these metrics are intrinsically derived, independently for each stream, via empirical historical data (Appendix I) rather than regionally derived criteria such as that discussed by Roth et al. (1998), Smogor & Angermeier (1999a, 1999b, 2001), and McCormick et al. (2001). For example, a chief approach of many regional studies is to assess species richness against a line of maximum richness (for a stream of given order) broadly derived for that region (e.g., Fausch et al. 1984, 1990; Appendix III: North Carolina Div. Water Qual.). These graphic derivations are dependent on baseline data from a large number of regional streams, including index streams of exceptional quality. Such graphs based on streams remote to the area are not suitable for streams of the biogeographically complex Piedmont/Coastal Plain ecotone area of the lower Potomac and the lack of suitably unimpacted index streams would hinder their derivation locally based on extant faunas. Further, Smogor & Angermeier (1999a) actually found few applicable patterns in the way functional and taxonomic metrics vary in the region among different order streams and recommended empirical approaches until such patterns emerge. Anthropogenic effects on assemblages of stream fishes cannot be interpreted without comparison to benchmark empirical data (Grossman et al. 1990, Lohr & Fausch 1997) and therefore the use of historical data was invoked.

The ten metrics adopted in this study

(Appendix II), based on species richness, relative tolerances, and guild characteristics, were limited to those which could be responsive within the constraints of the area's faunal diversity. In modified form, eight of these roughly concur with some of the 14 metrics adopted by Angermeier et al. (2000) for bioassessment of upland streams in the Mid-Atlantic region, including three of those which varied most meaningfully in their studies (i.e., total number species, number of mineral substrate spawners, tolerant species present). However, such taxonomic metrics as numbers of sucker, sculpin, sunfish, and darter species were rejected for this study because of the natural lack of diversity or patchy distribution of some of these groups in the Plummers Island area. Some metrics chosen also concur with those of other regional studies, the more Coastal Plain oriented efforts of Scott & Hall (1997) and Roth et al. (1998), but, in addition to taxonomic metrics cited above, others were rejected because of different breakdowns in guild categories.

A few other commonly used metrics were rejected for, at least insofar as this study is concerned, what seemed to be biologically sound reasons. For example, numbers of individuals of various functional or taxonomic groupings are often included among IBI metrics, as are numbers of individuals of tolerant (or intolerant) species (e.g., Smogor & Angermeier 1999a). However, numerous studies (e.g., Schlosser 1985, Matthews et al. 1988, Gelwick 1990, Matthews 1998 and others) have found that, while species assemblages, in terms of species present, are generally fairly persistent through time and major natural disturbances (e.g., floods, droughts) of stream ecosystems, relative abundance of species can be quite variable due to these natural events (and thus partially independent of anthropogenic effects). Even so, stability estimates vary. Matthews (1986), Freeman et al. (1988) and Meffee & Berra (1988) found assemblages of eastern upland streams were persistent in terms of relative species abundance and production., though recruitment was variable in some species, probably correlated with environmental conditions, and there were differences among sites within streams. On the other hand, Grossman et al. (1990) reported high variability in stream assemblages, perhaps making it difficult to detect anthropogenic disturbances. Clearly, benchmark empirical data on natural variation in stream fish assemblages are necessary before anthropogenic effects can be deduced (e.g., Lohr & Fausch 1990). While it is tempting to include what, in some cases, seem to be obvious numerical dominance of species rated as tolerant, or of various functional groupings, in Plummers Island areas streams, this was refrained from because of uncertainties in natural variation just discussed. Species regarded as tolerant may exhibit numerical dominance in situations involving both degraded and more pristine habitats, especially in smaller streams (pers. observ.). Mere persistence of species, generally agreed upon as being less susceptible to natural phenomena than relative abundance, were therefore chosen as more applicable metrics. While Grossman et al. (1985) concluded that persistence, based on the presence or absence of species, may be an inappropriate criterion for quantification of assemblage organization, determination of such organization is not a primary aim of an IBI and its retention as metric criteria seems appropriate. The efficacy of an IBI or other bioassessment approaches may be initially compromised by lack of understanding of natural variations in species assemblage. However, by its very nature, the easily repeatable methodology of the IBI, in combination with water quality data and logging of stochastic natural events, may facilitate the eventual teasing apart of variation associated with these factors.

Another commonly used metric, presence or absence of diseased fishes was not employed in this study. No obviously diseased fish were noted at any of the sample sites; thus addition of this metric would have equally raised the ratings of each site across the board. In the event that diseased fishes are encountered at any of these sites in the future, for comparative purposes, use of this metric could be considered by upwardly adjusting all sites in the current study and accordingly down-rating those sites with diseased fish at future dates.

Karr et al. (1986) and Smogor & Angermeier (1999a, 1999b) recommended that the percentage of species rated as tolerant in a region should be kept low, perhaps 10–15%, in order to assure that this metric reflects only the lower end of the biotic integrity continuum, though Smogor & Angermeier (1999a) also acknowledged that a 0.50 occurrence of these species may be normal in smaller streams of the Virginia region. Eight of 39 (or 20%) expected species (Appendix II) in Plummers Island area tributaries are rated as tolerant based on a consensus of sources. Inspection of Appendix I reveals that three of these species are widely successful (i.e., probably high tolerance), introduced species that have inflated this component. It is felt that reclassification of any species here treated as tolerant in order to conform to the above criteria would result in flawed assessments (i.e., artificially high) of biotic integrity and this slightly higher percentage is retained for the analysis. Those authors also recommended only 10% or less of species in a region be classified as intolerant to maintain sensitivity to high biotic integrity. The five of 39 (12%) species so classified herein (Appendix II) approximates that criterion.

Some metrics used in this and all other IBI studies seem inherently redundant and may raise concerns about "double counting" or unduly weighting the significance of the presence of certain species. For example, as noted above successfully introduced species correspondingly usually are rated as tolerant and the two metrics based on numbers of nonnative species and tolerant species, respectively, may therefore seem non-independent. However, inspection of Appendix II reveals that some nonnative species (e.g., *Pimephales notatus, Lepomis cyanellus*), which apparently were successfully naturalized for a time (Appendix I), are no longer present in some or all streams or are locally extirpated while some purportedly less tolerant native species remain. The assumed relationship between successful nonnative status and tolerance may not be well understood and thus maintaining some independence of these metrics is warranted. Similar concerns might arise over the obvious positive correlation between such metrics as total species present and metrics based on the numbers of representatives of various guilds present. But elimination of various guild metrics would be to sacrifice independent tools which may afford insight on how biotic integrity is responding to environmental alterations.

Some IBI studies (e.g., North Carolina Div. Water Qual.) disregard young-of-year age classes in scoring presence/absence of species related to various metrics. However, arbitrary exclusion of individuals that, especially in the case of short-lived species, may have attained 30 percent of their adult life span (e.g., Grossman et al. 1985) seems to ignore strong evidence of species persistence and young-of-year are here accorded equal status. Moreover, the multiple year class metric used herein addresses any concerns about suspect recruitment success.

The employment of shorter but intensively sampled reaches in this study differs from that of many other IBI applications which typically employ standardized, single electroshocker passes over longer reaches. These may range from one to six hundred meters. Angermeier & Karr (1986) have recommended minimum 300 m reaches to assure adequate sampling for species richness and other aspects by single pass methods. However, in connection with population estimates, Riley & Fausch (1992) maintained the efficacy of single pass sampling is limited (e.g., Bohlin & Sundstrom 1977, Peterson & Cederholm 1984) and recommended three or more passes per sample reach. While studies aimed at IBI assessment and population estimates differ in their aims, the implications for under sampling of species important to metrics are implicit. In this study, with the limited accessibility and collecting constraints in heavy residential and park land areas, the employment of long sample reaches was not practical. However, it is felt that the intensive, near total removal method in shorter but physically diverse reaches overcomes this limitation. Bayley and Peterson (2001) have demonstrated that total species presence is often (86% of times) not revealed by standard gear methods. Their standard methods employed limited pass efforts to estimate richness. Total richness, against which these efforts were tested, was determined by total removal methods, much the same as utilized herein. Moreover, Lohr & Fausch (1997), in a rigorous comparative study, found only limited increments of species richness added with increased scale and that robust estimates of species richness were obtained by thoroughly sampling two contiguous riffle/pool units in smaller streams much the same as was conducted in this study except for the two largest stream sites. Hill & Grossman (1987) have demonstrated that 30 m encompasses the home range of many small upland stream species further validating such a reach as a meaningful sampling unit. Inspection of Appendix II for expected occurrences reveals, in the experience of the author, that missing species are not generally those that tend to be rare and localized in streams where they occur, but instead are rather ubiquitous throughout, with the possible exception of *Notropis amoenus,* which, as has already been noted, may be extirpated from the entire area. Therefore, even though they might persist in other portions of a given tributary system, their absence from an IBI study reach is significant.

Freeman et al. (1988) found significant variation in fish assemblage stability at different sites within stream systems and Matthews (1986, 1998) and Ross et al. (1985) have pointed out longitudinal zonation phenomena in species compositions in stream fishes with respect to changing physical habitat and stream order and the importance of sampling multiple, individually analyzed sites. Multiple, spatially well separated, intensively sampled sites were employed in this study where possible to accommodate these concerns and intuitively would better address them then would single, linearly more extended sites commonly used in other IBI studies.

In order to prevent artificially high expectations of species or species richness for smaller streams based on empirical data, care was exercised in including only those species known to occur in the habitat types, with respect to stream order and physical habitat, that comprised the respective sample sites. Historical records upon which these expectations are based are vouchered via museum specimens but exact sampling sites within those streams are not known. Some of the samples of McAtee & Weed (1915) may have been from very near the mouths of these streams, hence the care taken to ascertain which of included species would also be expected in more upstream reaches. Such adjustments are important to accurate assessments of biotic integrity (Osborne et al. 1992). Only in the case of *Notropis amoenus* was there some doubt with regard to inclusion. Throughout much of its range (New York to South Carolina) this species is a denizen of medium and larger streams, though Snelson (1968) stated that it inhabits smaller streams in more northerly portions of that range and Jenkins & Burkhead (1993) map some populations in smaller streams of northern Virginia. This minnow now seems to be extirpated from the entire study area (Appendix I); thus the nature of it's occurrence is hard to evaluate. However, removal of this single species would effect only very minimal upward adjustments in ratings of biotic integrity. No unexpected species were found at study sites which might have required adjustments in rating criteria.

Results and discussion.—Examination of the results of IBI analyses (Appendix II) are strongly indicative of generally depressed stream health in tributaries examined throughout the Plummers Island study area. Based on the rating scale devised for this study, the current compositions of fish communities at sample sites indicate that habitat quality ranges from poor to good. Only one stream, Turkey Run, was rated as Poor with an IBI score of 20 (of possible 50). However, five other sites rated as Fair had scarcely higher scores, bordering on Poor. These were the upper and lower Dead Run sites, Scott and Bullneck runs, and the lower Cabin John run site. Surprisingly however, for an area of considerable suburban development, four sites, including three Difficult Run sites and the lower Rock Run site, were actually rated as Good by the IBI. Furthermore, three sites rated as Fair (lower Difficult Run, Old Farm Cr., upper Rock Run) actually closely approached scores that would have yielded a Good rating. No sites closely approached an excellent rating with the highest rated site, Difficult 4 (Little Difficult Run), scored at 36, falling well short of the required 41.

Examination of Appendix II reveals that every sample site probably has had a few to many, otherwise relatively ubiquitous, species extirpated from it, or they may have been reduced to levels that negate consistent capture. These include many species rated has having medium or high tolerance. Some examples are *Campostoma anomalum, Clinostomus funduloides, Luxilus cornutus, Notropis procne, Hypentelium nigricans, Noturus insignis, Lepomis auritus,* and *Etheostoma olmstedi.* These species are persistent in many other streams peripheral to the Plummers Island study area (e.g., Appendix III: Yarrington 1990 and Montgomery Co. Dept. Environ. Prot. Data). The Tessellated Darter, *Etheostoma olmstedi,* remains particularly successful in the surrounding area (e.g., Yarrington, 1994). These conspicuous absences from several study site samples are indicative of the magnitude of the depressed biotic integrity in some of the Plummers Island area streams.

Those smaller streams (i.e., Turkey, Dead, Scott, and Bullneck runs) with lowest cumulative IBI scores (Poor to Fair ratings) tended to score low on all metrics positively correlated with stream health except that related to recruitment (percentage species 2 + age classes present) and to presence of nonnative species (Appendix II). Fifty- to one hundred-percent of species present in these streams were represented by multiple year classes so, while numbers of overall species are reduced, those remaining continue to exhibit relatively healthy populations. All four streams had greatly depressed numbers of native and total species present relative to that expected as well as representatives of all feeding and reproductive guilds employed in the metrics. No guild has been particularly more successful at persisting in these streams than any other. Especially noteworthy were the extremely reduced numbers of substrate manipulator spawners, species that might be expected to overcome a certain amount of the effects of siltation via this manipulation (e.g., Smogor & Angermeier, 1999b). However, these fishes fared worse or no better than simple mineral substrate spawners did. Possible reasons for this are discussed below. Scores were further reduced by the relatively high percentages of tolerant (versus lower tolerance) species present in these streams.

The larger stream with a low IBI score, lower Cabin John Run (22), scored low on eight of ten metrics but, unlike smaller streams with low scores, did not score high for recruitment of those few species that remained present. Again, both numbers of expected native and nonnative species were greatly depressed as were representatives of all guilds used in the metrics. Surprisingly, and unlike the smaller streams, Cabin John did not have a disproportionately high number of tolerant species present. Possible reasons are discussed below.

Those streams with Good ratings, the three remaining Difficult Run sites and lower Rock Run, all medium to small creeks, showed increased scores over other streams of comparable size generally across the board in all metrics except nonnative species present and recruitment. Consistently higher scores were realized from the proportionately lower number of tolerant species present in these streams and, directly related to increased numbers of overall species, the increased numbers of representatives of all feeding and reproductive guilds, particularly benthic insectivores and simple mineral substrate spawners.

Examination of the guild metrics reveals a plausible explanation for the tolerant nature of the few species that persist in the most degraded streams of the Plummers Island area. This reasoning also seems circuitously applicable to some odd results of the lower Cabin John Run sampling. The consistently most resilient species in all streams are two daces, *Rhinichthys atratulus* and *R. cataractae,* and the Creek Chub, *Semotilus atromaculatus.* The daces both belong to the benthic insectivore and simple substrate spawner guilds (Appendix II). Other members of these guilds have been eliminated from these streams in many cases. However, only the *Rhinichthys* species both feed and spawn in the swiftest portions of riffles. They are thus most assured of purgation of silt or excessive periphytic growth in the habitat that supports two major facets of their ecology. While larval dace inhabit slacker habitats along stream margins (McPhail & Lindsey 1970), they feed above the bottom on planktonic organisms then move back into more current-swept areas at an early age (Traver 1929), thus probably reducing their susceptibility during early life history stages. The White Sucker, *Catostomus commersoni,* exhibits somewhat similar habits and some measure of resilience (Appendix II), even though the consensus tolerance rating for this species is medium. The Creek Chub, on the other hand, while an inhabitant of pool areas, feeds heavily at the surface on fallen insects and constructs clean gravel nests in which to spawn, thus possibly overcoming the effects of siltation or algal growth. Substrate manipulator spawners (e.g., *Nocomis*) may successfully avert depressed spawning success due to siltation but succumb to it in later life if they typically feed on benthos in less current-swept areas. Further, loss of keystone gravel nest-building species, such as *Nocomis* (e.g., from Cabin John Run, Appendix I) collaterally effects communal spawning associates (e.g., *Notropis rubellus*) and may result in their demise. Tolerant species, then, possess a combination of habits that reduce their vulnerability to degraded habitats while those with other combinations have been less successful in Plummers Island area streams. Smogor & Angermeier (1999b) found correlations suggesting that generalists and tolerant species may be somewhat synonymous. However, guild combinations may be more important.

While the lower Cabin John sampling yielded a low IBI score, it scored surprisingly high in the metric related to percentage of tolerant species, having only three of nine species present regarded as tolerant, a score comparable to that found for this metric in streams with Good ratings. Inspection of the data (Appendix II) reveals that this is brought about by the presence of six species of medium tolerance, including the aforementioned White Sucker whose tolerance rating may eventually deserve reconsideration, in the face of an overall reduced number of species from that expected. Two species, the Stoneroller, *Campostoma anomalum,* and the introduced Greenside Darter, *Etheostoma blenniodes,* possess combinations of characteristics that may sustain them. The Stoneroller is a benthic herbivore and a substrate manipulator while the Greenside Darter exhibits characteristics roughly similar to *Rhinichthys* (above). Two centrarchids, the Redbreast Sunfish and introduced Smallmouth Bass, are midwater or surface predators and substrate manipulators. It is also very possible that these species are additionally recruiting from the nearby Potomac River, thus artificially skewing this metric. It is important to point out that such recruitment is very likely nonexistent or much reduced at sites in other streams sampled because of the highly precipitous nature of their lower courses and, in most cases, difference in stream order and thus is not a factor in evaluating their metrics, negating the earlier mentioned concerns of Osborne et al. (1992).

Future applications of IBI sampling at sites selected for this study, conducted and analyzed as described herein, should yield insights on trends in biotic integrity and, by extension, habitat quality in Plummers Island area streams. It may also test or shed additional light on subtrends tied to various components (i.e., guilds) of the fish fauna as well as hypotheses posed concerning their relative tolerances and persistence.

Conclusions

Examination of the history of occurrence and distribution of fishes in the vicinity of Plummers Island, Maryland, reveals a moderately diverse native fauna of approximately 56–60 species. About 25% of these species are, or were, mainly confined to the main Potomac River by habitat preferences. The remainder were largely restricted to tributaries or were ubiquitous.

The lower Potomac and Plummers Island area have been particularly bombarded with introductions of nonnative fish species, both of North American and Eurasian origin, for well over a century. No fewer than 30 were naturalized for a time, or continue to be introduced, and 22 remain an integral part of the fauna today. Of the total 86 native and nonnative species recorded from the area, only 62 are known to persist in the area today.

A few, otherwise more generally distributed fishes have enigmatic distributional patterns in the fall line ecotone area with no records of occurrence in some heavily sampled tributary streams with seemingly suitable habitat in the study area. For instance, when comparing numbers of expected species (Appendix II) among the largest tributary watershed, Difficult Run in Virginia, and smaller watersheds, such as Cabin John Run in Maryland, conventional predictions, i.e., those employed in many IBI criteria, would predict greater species richness for the larger basin. But this is not borne out by historical data (Appendix I) from this well-collected watershed and the conspicuous absence of such species as the Silverjaw Minnow, Comely Shiner, Rosyface Shiner, Shorthead Redhorse, Trout-perch, Potomac Sculpin, and some possibly introduced species (e.g., Golden Redhorse, Greenside Darter) from Difficult Run appear to constitute elements of a real pattern. Clearly, fishes, in general, are more continuously distributed on the Maryland versant of the Potomac transecting the study area. The precipitous lower reaches of Virginia tributaries, such as Difficult Run, present to a much lesser extent in Maryland tributaries, may impede colonization by species introduced to the Potomac in recent decades. Whether this mechanism is a factor in the history of native fishes is speculative but must be considered, especially if natural extirpations occurred during the Pleistocene and post-glacial recolonization has been selectively constrained by gradient barriers.

Converse to the above pattern, historical data also show that several of the smaller tributaries in the study area had species richness exceeding that which regional IBI criteria, deriving from modern sampling, might predict. These phenomena demonstrate the fallibility of applying broadly derived regional IBI rating criteria to streams in this complex ecotonal area and the importance of a tailored approach as utilized herein.

There is some evidence that the C & O Canal may have served as a conduit for lowland species to traverse the study area and to circumvent the precipitous Fall Line reach of the Potomac, thus introducing a significant anthropogenic element into current distributions. Daniels (2001) has cautioned that, in New York, the role of canals in fish dispersal may have been overestimated in the absence of empirical evidence. However, the potential of the C & O Canal to entrain lowland and large river species at its Georgetown terminus in D. C., and, in succession, through its series of locks up river, must be recognized and is documented by occurrences of such species as Gizzard Shad and Chain Pickerel within it (McAtee & Weed 1915). The occurrences of Gizzard Shad, as well as Bowfin, White catfish, and especially, Eastern Mudminnow, in habitats above the Fall Line may owe to this passage.

Analyses of present day occurrences and distribution of fishes compared to historical data reveal a much depressed native fauna in many tributary streams and, to a lesser extent, the main Potomac River. Indices of biotic integrity (IBIs), especially devised for application to Plummers Island area tributaries, were effective in indicating not only the degree to which biotic integrity, and therefore stream health, has been negatively effected in the area, but also gave insight as to how various faunal elements may respond to stresses on those streams. Despite the pervasive urbanization in watersheds of area streams, biotic integrity remains surprisingly good at a few sites, mainly in the Difficult Run system and lower Rock Run. These exceptions might be attributed to preservation of extensive riparian woodland buffers in these systems. On the other hand, while all area tributaries have these buffers to some degree, in some cases they apparently have not been sufficient to overcome the negative impacts of suburban runoff at points of ingress along their courses, exacerbated by extensive impervious surfaces within watersheds, resulting in poor biotic integrity. Larger, multibranched systems, such as Cabin John and Difficult Runs, suffer degraded integrity in lower reaches compared to smaller, more linear, systems (e.g., Dead and Rock runs), probably reflecting cumulative impacts inflicted across the diverse land usage they drain. In these streams, then, a negative relationship exists between watershed size and species richness, controverting the expected positive relationship assumed by IBI rating criteria.

The fact that a few streams in the study area maintain relatively good biotic integrity and compliments of native species lends encouragement that others could recover with improved conditions. Hopefully, increased awareness and enforcement of environmental regulations can provide that improvement. It is recommended that bioassessments, such as the IBIs presented herein, be repeated periodically to monitor positive or negative trends in fish community composition and stream health. These results might be considered heavily in regional and local policy-making, planning, and enforcement decisions related to water quality.

Acknowledgements

Efforts to assimilate collections data on fishes and other information used in this report were greatly aided by several persons. For assistance with field surveys I thank R. T. Bryant, B. J. Archibald, E. Archibald, C. Lea, K. Cieminski, and D. Ingram. I especially thank J. M. Clayton for assistance both in the field and with repeated requests for information on collections in USNM. J. F. Finan, S. L. Jewett, L. F. Palmer and S. J. Raredon facilitated loans of USNM specimens. G. M. Hogue and L. F. Womack curated voucher specimens at NCSM. For providing agency data or collections information I thank P. F. Kazyak and S. Stranko (MD Department of Natural Resources), B. P. Yarrington and J. M. Mudre (George Mason University and Federal Energy Regulatory Commission), J. D. Cummins (Interstate Commission on Potomac River Living Resources), S. L. Leathery (National Oceanic & Atmospheric Administration), A. May and L. Thornburg (Fairfax Co. Stream Protection Strategy Program), J. Hennessey

(MD Department of the Environment), S. Eyler and S. A. Welsh (U.S. Fish & Wildlife Service), M. Haddaway and K. Van Ness (Montgomery Co. Department of Environmental Protection), and R. L. Raesly (Frostburg State University, MD). I especially thank I. Palmer and M. J. Siemien (D. C. Fisheries & Wildlife Branch) for loan of a backpack electroshocker and provision of data. R. E. Jenkins, Roanoke College, addressed numerous questions on Potomac River fish records. P. Toops and D. Sealey of the National Park Service provided permits and historical information and additional permits were provided by W. P. Jensen (MD Department Natural Resources) and R. K. Wajda (VA Department of Inland Fish and Game). B. H. Tracy (North Carolina Division of Water Quality) provided abundant information on IBIs. This paper benefited from two anonymous reviewers and J. D. Cummins, R. E. Jenkins, P. F. Kazyak, and B. P. Yarrington commented on an earlier draft and provided valuable additional information. J. Raine (NCSM) assisted with ArcView and preparation of Fig. 1.

This study was made possible through the generosity and vision of the Washington Biologists Field Club via a grant to the author and his then employer, the Smithsonian Institution. My sincere thanks go to the late C. O. Handley and to R. W. McDiarmid, D. H. Nicolson, D. E. Wilson, and especially J. C. Tyler, for their roles in facilitating this funding.

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Appendix I—Historic and present occurrence and native status for fish species in Potomac River (including C&O Canal) and seven tributaries in vicinity of Plummers Island, Maryland. Native status is given as N (native) or I (introduced). Years of occurrence are based on following sources: 1861–1899 (except 1876) = Smith and Bean (1899) and USNM records; 1876 = approximate date from Uhler and Lugger (1876) unless otherwise footnoted; 1901–1942 (except 1938) = Bean and Weed (1911), McAtee and Weed (1915), confirmed by USNM records, plus miscellaneous USNM records; 1938 = Lee et al. (1981); 1944 = surveys of R.R. Miller et al. (as reported by Manville 1968); 1955 = Appendix III: Sanderson 1955; 1974 = Appendix III: Dietemann 1975; 1976a = Appendix III: Deitemann & Sanderson 1976; 1978a = Appendix III: Speir and Early 1978; 1960, 1961, 1962 = Nichols (1968); 1975, 1976b, 1978b, 1982, 1983, 1985, 1986a, 1989 = Appendix III: Yarrington 1990, Kelso et al. 1991; 1992a = Appendix III: Odenkirk 1992; 1984 = Cummins (1985); 1985 = Appendix III: Cummins & Lubbers 1985; 1986b = Appendix III: Buckley & Nammack 1987; 1987 = Appendix III: Vadas 1987; 1992b, 1993, 1994 = Appendix III: Tilak & Siemien 1992, 1993, 1994; 1995 = present study; 1996a = Leathery (1999); 1996b = Appendix III: Montgomery County Department of Environmental Protection; 1999 = Appendix III: Fairfax County Stream Protection Strategy; C and 1979 = circumstantial or actual occurrence based on records in Jenkins and Burkhead (1993) and Christmas et al. (1998).

FAMILY/Species (Native Status)	Turkey Run	Dead Run	Scott Run	Bullneck Run	Difficult Run	Cabin John Run	Rock Run	Potomac R./C&O
FAMILY PETROMYZONTIDAE—lampreys								
Petromyzon marinus Sea Lamprey (N)						1944		1899 1905 1960
FAMILY ACIPENSERIDAE—sturgeons								
Acipenser brevirostrum Shortnose Sturgeon (N)								1876
Acipenser oxyrinchus Atlantic Sturgeon (N)								1874 1899
FAMILY LEPISOSTEIDAE—gars								
Lepisosteus osseus Longnose Gar (N)								1861 1899
FAMILY AMIIDAE—Bowfin								
Amia calva Bowfin (N?)								C & 1979
FAMILY ANGUILLIDAE—freshwater eels								
Anguilla rostrata American Eel (N)	1995 1999	1976b 1995	1995	1983 1995 1999	1975 1982 1986a 1989 1992a 1995 1999	1944 1974 1987 1995 1996a	1912 1974	1899[21] 1912 1976a 1978a 1986b 1992b 1996a
FAMILY ENGRAULIDAE—anchovies								
Anchoa mitchelli Bay Anchovy (N)								1984
FAMILY CLUPEIDAE—herrings & shads								
Alosa aestivalis Blueback Herring (N)								1899[22] 1961 1962 1986b 1992b
Alosa mediocris Hickory Shad (N)								1876 1899[21]

Appendix I—Continued.

FAMILY/Species (Native Status)	Turkey Run	Dead Run	Scott Run	Bullneck Run	Difficult Run	Cabin John Run	Rock Run	Potomac R./C&O
Alosa pseudoharengus Alewife (N)								1876 1961 1962 1986b 1992b
Alosa sapidissima American Shad (N)								1876 1899[24] 1961 1962 1993/4
Dorosoma cepedianum Gizzard Shad (N)								1876 1899 1905 1912 1976a 1978a 1984 1996a 1986b 1992b
Dorosoma petenense Threadfin Shad (I)								C
FAMILY CYPRINIDAE—minnows								
Campostoma anomalum Central Stoneroller (N)	1912				1986a 1989 1995 1999	1987 1995 1996a		1996a
Carassius auratus Goldfish (I)						1996a		1876 1899 1976a 1978a 1986b 1992b
Clinostomus funduloides Rosyside Dace (N)	1912[2]	1983 1995	1912[2]	1912[2] 1995	1912[2] 1975 1982 1986a 1989 1992a 1995 1999	1912[2] 1944[2] 1974 1995 1996a	1912[2] 1974 1995 1996b	1996a
Ctenopharyngodon idella Grass Carp (I)								C
Cyprinella analostana Satinfin Shiner (N)	1912[3]		1912[3]		1901 1989 1995 1999	1912[3] 1974[3] 1996b	1912[18] 1974[3]	1899? 1912 1976a 1985
Cyprinella spiloptera Spotfin Shiner (N?)					1999	1974[12]	1974[12]	1899? 1912[32] 1922 1976a[32] 1984[32] 1995 1996a

Appendix I—Continued.

FAMILY/Species (Native Status)	Turkey Run	Dead Run	Scott Run	Bullneck Run	Difficult Run	Cabin John Run	Rock Run	Potomac R./C&O
Cyprinus carpio Common Carp (I)						1996b		1899 1912 1955 1960 1976a 1978a 1984 1986b 1992b 1995 1996a
Ericymba buccata Silverjaw Minnow (N?)	1912					1909–10 1987 1994 1995 1996b		1906
Exoglossum maxillingua Cutlips Minnow (N)					1975 1986a 1989 1995 1999	1912 1944 1987 1996b	1912 1974 1995 1996b	
Hybognathus regius Eastern Silvery Minnow (N)	1912[4] 1999?							1876 1899[4] 1984[4] 1986b 1992b
Leuciscus idus Ide (I)								1899
Luxilus cornutus Common Shiner (N)	1912[5]				1975[5] 1986a[5] 1989[1] 1992a 1995 1999	1912[5] 1944[5] 1974[5] 1987[5] 1995 1996b	1912[5] 1974[5]	1912[5] 1984[5] 1992b 1995
Margariscus margarita Pearl Dace (N)						1899[30] 1909[18]		
Nocomis micropogon River Chub (N)					1986a 1992a[34]	1912[6] 1944[28]		1899[6] 1912[6] 1955 1976a 1978a 1984 1985
Notemigonus crysoleucas Golden Shiner (N)					1975 1999	1912		1912 1955 1984 1986b 1992b 1995 1996a
Notropis amoenus Comely Shiner (N)	1912		1912			1909 1910[7,9]	1912[8]	1899[8] 1912[8]
Notropis bifrenatus (N) Bridle Shiner								1908[18]

Appendix I—Continued.

FAMILY/Species (Native Status)	Turkey Run	Dead Run	Scott Run	Bullneck Run	Difficult Run	Cabin John Run	Rock Run	Potomac R./C&O
Notropis hudsonius Spottail Shiner (N)	1912				1989 1999	1912 1974 1996b	1912	1899 1912 1978a 1984 1985 1986b 1992b 1995 1996a
Notropis procne Swallowtail Shiner (N)		1912[18]			1975 1989 1995 1999	1912 1944 1987 1995 1996b		1899 1976a 1978a 1992b 1995 1996a
Notropis rubellus Rosyface Shiner (N)						1912[9]	1912[19]	1984 1995
Pimephales notatus Bluntnose Minnow (I?)	1912 1999		1912 1983	1893	1975	1909 1912 1974 1996b	1912 1974	1909 1912 1929 1976a 1984 1985 1992b 1995 1996a
Pimephales promelas Fathead Minnow (I)					1995 1999			
Rhinichthys atratulus Blacknose Dace (N)	1912[10] 1995 1999	1912[10] 1976 1983 1995 1999	1912[10] 1993 1995 1999	1995 1999	1912[10] 1975 1982 1986a 1989 1992 1995 1999	1912[10] 1944 1974 1987 1995 1996b	1912[10] 1974 1995 1996b	1912[10]
Rhinichthys cataractae Longnose Dace (N)	1995 1999		1912 1983	1983 1995 1999	1975 1982 1986a 1989 1992a 1995 1999	1912 1944 1974 1987 1995 1996b	1912 1974 1995 1996b	1912
Semotilus atromaculatus Creek Chub (N)	1912 1999	1912 1976 1999	1912 1983 1999	1995 1999	1912 1982 1986a 1992a 1995 1999	1912 1944 1974 1987 1995 1996b	1912 1974 1995 1996b	1912
Semotilus corporalis Fallfish (N)					1999?	1912 1944 1996b		1955 1996a
Tinca tinca Tench (I)								1899

Appendix I—Continued.

FAMILY/Species (Native Status)	Turkey Run	Dead Run	Scott Run	Bullneck Run	Difficult Run	Cabin John Run	Rock Run	Potomac R./C&O
FAMILY CATOSTOMIDAE—suckers								
Carpiodes cyprinus Quillback Carpsucker (N)								1899 1912 1978a 1984 1992b 1996a
Catostomus commersonii White Sucker (N)	1999	1976 1983 1995 1999	1912 1983 1995 1999		1975 1982 1986a 1989 1992 1999	1912 1944 1974 1995 1996b	1912 1974 1995 1996b	1899 1912 1955 1976a 1978a 1984 1992b
Erimyzon oblongus Creek Chubsucker (N)							1913	1899 1912[11] C
Hypentelium nigricans Northern Hogsucker (N)	1912				1986a 1995 1999	1912 1974	1912 1974	1899 1912 1955 1978a 1995 1996a
Moxostoma erythrurum Golden Redhorse (I?)						1996b		1992b
Moxostoma macrolepidotum Shorthead Redhorse (N)						1912		1899 1955 1976a 1978a 1992b 1996a
FAMILY ICTALURIDAE—bullhead catfishes								
Ameiurus catus White Catfish (N)								1876 1899 1912 1978a 1992b
Ameiurus natalis Yellow Bullhead (N)	1999		1995	1999	1999		1995 1996b	1899 1912 1955 1976a 1978a 1992b 1995
Ameiurus nebulosus Brown Bullhead (N)					1975 1999			1899 1912 1976a 1986b 1992b
?*Ictalurus furcatus* Blue Catfish (I)								1905? 1912? 1955? 1992b?

Appendix 1—Continued.

FAMILY/Species (Native Status)	Turkey Run	Dead Run	Scott Run	Bullneck Run	Difficult Run	Cabin John Run	Rock Run	Potomac R./C&O
Ictalurus punctatus Channel Catfish (I)						1974		1889 1899 1907 1955 1960 1976a 1978a 1984 1986b 1992b
Noturus gyrinus Tadpole Madtom (N)								1911[27]?
Noturus insignis Margined Madtom (N)					1982 1986a 1989 1995 1999	1912[12]	1912[12] 1995 1996b	1876 1899 1912[12] 1976a 1978a
FAMILY UMBRIDAE—mudminnows								
Umbra pygmaea Eastern Mudminnow (N)					1999?			C
FAMILY ESCODIAE—pikes								
?*Esox lucius* Northern Pike (I)								1993?
Esox niger Chain Pickerel (N)								1912[1] C
FAMILY SALMONIDAE—salmons and relatives								
Salmo trutta Brown Trout (I)					1982 1986a 1992a			
Salvelinus fontinalis Brook Trout (I?)					1899 1927 1975 1978b 1982			
FAMILY PERCOPSIDAE—trout-perches								
Percopsis omiscomaycus Trout-perch (N)						1899[13]	1899[13]	1876 1906 1911
FAMILY ATHERINIDAE—silversides								
Menidia beryllina Inland Silverside (N)								1984 1986b 1992b
FAMILY BELONIDAE—needlefishes								
Strongylura marina Atlantic Needlefish (N)								1899[26] 1992b
FAMILY FUNDULIDAE—killifishes								
Fundulus diaphanus Banded Killifish (N)								1910 1914 1926 1984 1986b 1992b

Appendix I—Continued.

FAMILY/Species (Native Status)	Turkey Run	Dead Run	Scott Run	Bullneck Run	Difficult Run	Cabin John Run	Rock Run	Potomac R./C&O
FAMILY POECILIIDAE—livebearers								
Gambusia holbrookii Eastern Mosquitofish (N)		1999						
FAMILY COTTIDAE—sculpins								
Cottus girardi Potomac Sculpin (N)						1944[31] 1987? 1996b		
FAMILY MORONIDAE—temperate basses								
Morone americana White Perch (N)								1876 1912 1961 1962 1984 1986b 1992b
Morone saxatilis Striped Bass (N)								1876 1912[14] 1962 1986b 1992b 1993
FAMILY CENTRARCHIDAE—sunfishes								
Ambloplites rupestris Rockbass (I)							1912	1899 1912 1955 1996a
Chaenobryttus gulosus Warmouth (I?)					1999		1912	1899 1912 1993 1996a
Enneacanthus gloriosus Bluespotted Sunfish (N)								1899[33] 1926
Lepomis auritus Redbreast Sunfish (N)	1912 1999		1912		1912 1989 1999	1912 1995 1996b	1912 1974 1995	1899 1912 1955 1976a 1978a 1992b 1995 1996a
Lepomis cyanellus Green Sunfish (I?)				1999	1975 1982 1989 1995 1999	1974 1996b	1911 1912 1974 1995 1996b	1912 1984 1992b

Appendix I—Continued.

FAMILY/Species (Native Status)	Turkey Run	Dead Run	Scott Run	Bullneck Run	Difficult Run	Cabin John Run	Rock Run	Potomac R./C&O
Lepomis gibbosus Pumpkinseed (N)	1912		1912 1995 1999		1912 1975 1995 1999	1912 1974 1996b	1912 1974	1899 1912 1955 1978a 1984 1985 1986b 1992b 1995 1996a
Lepomis macrochirus Bluegill (I)			1999	1995 1999	1975 1982 1986a 1989 1992a 1995 1999	1974 1996b	1974 1995	1900[15]? 1910 1955 1978a 1984 1985 1992b 1995 1996a
Lepomis megalotis Longear Sunfish (I)					1975 1999			1911[35]? 1984 1985 1992b 1995 1996a
Lepomis microlophus Redear Sunfish (I)								1995
Micropterus dolomieu Smallmouth Bass (I)	1999		1912		1912 1975 1986 1989 1992	1995 1996b	1974	1899 1912 1955 1976a 1978a 1984 1985 1992b 1995 1996a
Micropterus salmoides Largemouth Bass (I)			1999	1995	1982 1986a 1989 1992a 1999	1974 1996b	1974	1876[16]? 1899 1911 1955 1978a 1984 1985 1986b 1992b 1996a
Pomoxis annularis White Crappie (I)								1894 1907 1914 1976a 1978a 1984 1993

Appendix I—Continued.

FAMILY/Species (Native Status)	Turkey Run	Dead Run	Scott Run	Bullneck Run	Difficult Run	Cabin John Run	Rock Run	Potomac R./C&O
Pomoxis nigromaculatus Black Crappie (I?)					1975			1894 1912[16] 1955 1978a 1992b 1995
FAMILY PERCIDAE—perches								
Etheostoma blennioides (I) Greenside Darter						1995		1976a
Etheostoma flabellare Fantail Darter (N)	1999				1989 1992 1999	1909 1944 1996b	1912 1974 1995 1996b	
Etheostoma olmstedi Tesselated Darter (N)	1912[17]		1912[17]		1975 1982 1986a 1989 1995 1999	1912[17] 1944[29] 1974 1987 1995 1996b	1912[17] 1995 1996b	1912[17] 1976a 1986b 1992b 1996a
Perca flavescens Yellow Perch (N)								1912 1984 1986b 1992b
Percina caprodes Logperch (N?)								1876 1899 1938
Percina notagramma Stripeback darter (N)								C?
Percina peltata Shield Darter (N)								1899[25] 1926 1976a?
Stizostedion vitreum Walleye (I?)								1901 1913 1916 1942 1992b

[1] as *Esox reticulatus*; [2] as *Leuciscus* or *Clinostomus vandoisulus*; [3] as *Notropis analostanus*; [4] as *Hybognathus nuchalis*; [5] as *Notropis cornutus*; [6] as *Hybopsis kentuckiensis*; [7] perhaps confounded, in part, with *Notropis rubellus*; [8] in part, as *Notropis photogenis* (a species not occurring on Atlantic Slope); [9] perhaps as *Notropis arge*; [10] as *Rhinichthys atronasus*; [11] as *Erimyzon sucetta oblongus*; [12] as *Schilbeodes insignis*; [13] as *Percopsis guttatus*; [14] as *Roccus lineatus*; [15] possibly as *Lepomis pallidus*; [16] as *Pomoxis sparoides*; [17] as *Boleosoma olmstedi* and *B. effulgens*; [18] based on USNM records, species McAtee and Weed or contemporaries collected but failed to report in 1915; [19] as *Notropis amoenus*; [20] as *Acipenser sturio*; [21] as *Anguilla chrysypa*; [22] as *Pomolobus aestivalis*; [23] as *Pomolobus mediocris*; [24] as *Pomolobus pseudoharengus*; [25] as *Hadropterus peltatus*; [26] as *Tylosurus marinus*; [27] as *Schilbeodes gyrinus*; [28] as hybrids with *Luxilus cornutus*; [29] as *Etheostoma nigrum olmstedi*; [30] as *Leuciscus margarita*; [31] as *Cottus bairdii*; [32] as *Notropis spilopterus*; [33] part as *Enneacanthus obesus*; [34] as "bluehead chub"; [35] possibly as *Lepomis solis*; [36] 1876 *M. salmoides* from Bean and Weed (1911), not Uhler and Lugger (1876).

Appendix II—Expected and actual occurrences and IBI classifications and metrics scores of fish species at 1995 IBI sample sites in Potomac River tributaries in vicinity of Plummers Island, Maryland. Expected occurrences ("E") are based on historical data in Table 1 and other factors (Methods). Metrics scoring is explained in Methods. Abbreviations are: N = native, NN = nonnative, O = omnivore, MI = midwater insectivore, BI = benthic insectivore, BO = benthic omnivore, BH = benthic herbivore, P = piscivore, C = catadromous,

Species	IBI Class	Turkey Run	Dead Run 1	Dead Run 2
Anguilla rostrata	N, O, C, T	1–1, 2–1, 4–1	E	E
Campostoma anomalum	N, BH, SM, M	E	E	E
Clinostomus funduloides	N, MI, MS, M	2–10	E	E
Cyprinella analostana	N, MI, SM, M	E	E	E
Ericymba buccata	N, BI, MS, M	E	E	E
Exoglossum maxillingua	N, BI, MS, M			
Luxilus cornutus	N, MI, MS, M	E	E	E
Nocomis micropogon	N, BI, SM, M			
Notemigonus crysoleucas	N, O, V, T			
Notropis amoenus	N, MI, MS, I	E	E	
Notropis hudsonius	N, BO, V, I			
Notropis procne	N, BI, MS, M	E	E	
Notropis rubellus	N, MI, SM, I			
Pimephales notatus	NN, BO, SM, T	E	E	
Rhinichthys atratulus	N, BI, MS, T	0–22, 2–2, 3–9	1–24, 2–2	1–6, 2–26, 3–4
Rhinichthys cataractae	N, BI, MS, M	3–1	E	E
Semotilus atromaculatus	N, MI, SM, T	E	0–6, 1–2, 2–3, 5–1	2–6, 4–1
Semotilus corporalis	N, MI, SM, M			
Catostomus commersoni	N, BO, MS, M	E	1–4, 2–5, 4–1	3–1
Erimyzon oblongus	N, BO, MS, M			
Hypentelium nigricans	N, BI, MS, M	E	E	
Moxostoma erythrurum	NN, BI, MS, M			
Mosostoma macrolepidotum	N, BI, MS, M			
Ameiurus natalis	N, BI, SM, T			
Ameriurus nebulosus	N, BI, SM, T			
Noturus insignis	N, BI, SM, M	E	E	E
Salmo trutta	NN, MI, MS, M			
Salvelinus fontinalis	N, MI, MS, I			
Percopsis omiscomacus	N, BI, V, I			
Cottus girardi	N, BI, SM, M			
Lepomis auritus	N, MI, SM, M	E		E
Lepomis cyanellus	NN, MI, SM, T			
Lepomis gibbosus	N, MI, SM, M	E		E
Lepomis macrochirus	NN, MI, SM, T			
Micropterus dolomieu	NN, P, SM, M			
Micropterus salmoides	NN, P, SM, M			
Etheostoma blennioides	NN, BI, MS, M			
Etheostoma flabellare	N, BI, SM, M			
Etheostoma olmstedi	N, BI, SM, M	E	E	E

IBI Metrics and Scores

	Turkey Run		Dead Run 1		Dead Run 2	
Total Species Present/Expected	4/18 (.22)	2	3/16 (.18)	1	3/14 (.21)	2
Native Species Present/Expected	4/17 (.23)	2	3/15 (.20)	1	3/14 (.21)	2
Nonnative Species Present/Expected	0/1 (00)	5	0/1 (00)	5	0/0 (00)	5
Total Tolerant Species/Total species	2/4 (.50)	3	2/3 (.66)	2	2/3 (.66)	2
Percentage Species 2+ Age Classes Present	0.50	3	1.00	5	0.66	4
Mineral Substr. Simple Spawners Pr/Exp.	3/9 (.33)		2/9 (.22)	1	2/6 (.33)	2
Substrate Manipulator Spawners Pr/Exp.	0/8 (00)	0	1/6 (.16)	1	1/7 (.14)	1
Benthic Insectivores Present/Expected	2/6 (.33)	2	1/6 (.16)	1	1/5 (.20)	1
Midwater Insectivores Present/Expected	1/7 (.14)	1	1/5 (.20)	1	1/6 (.16)	1
Benthic Omnivores Present/Expected	0/2 (00)	0	1/2 (.50)	3	1/2 (.50)	3
Total IBI Score (of possible 50)		20		21		23
Habitat Rating	Poor		Fair		Fair	

Appendix 1I—Extended. MS = mineral substrate simple spawner, SM = substrate manipulator spawner, V = variable spawner, T = tolerant, MT = medium tolerant, I = intolerant. Occurrence data are given as size (age) class, with numbers 0 (young-of-year) through 6 denoting size classes for each species compiled across all sites sampled, followed by the number of individuals of that size present.

Scott Run	Bullneck R.	Difficult 1	Difficult 2	Difficult 3	Difficult 4
3–1	2–3, 4–2	E	2–1, 3–1, 5–1, 6–1	2–1, 5–1	0–1, 2–1, 4–1
E	E	E	1–1	E	E
E	3–4	1–3	2–6, 5–5	E	1–18, 2–21, 3–1
E	E	1–4, 2–1	2–1, 3–1	E	E
E	E	E	E	E	E
E		1–1	2–1	1–1	1–1
E	E	2–16, 3–1	1–5, 2–9, 3–5	2–2, 3–3	2–1, 3–1, 4–1
		E	E		
		E	E		
E		E	E		
		E	E		
E	E	2–2	2–1	E	
E	E	E	E	E	
0–2, 1–20, 2–9	1–18, 2–23, 3–3	1–6	0–10, 1–2, 2–10, 3–9	1–2, 2–7, 3–5	0–2, 1–18, 2–21
E	1–2, 3–6	2–2, 3–1	1–6, 2–11, 3–1	2–1	3–1
0–7, 1–2, 2–2 3–2, 5–1	1–1, 2–1	E	2–1	1–3, 2–2	1–15, 2–2, 3–2
		E	E		
1–5, 5–1	E	E	0–2, 5–1	2–3, 4–1	1–4, 2–1
		E	E		
E		1–1	1–3, 2–1	2–1	
3–1		E	E	E	
		E			
E	E	4–1	E	3–1	E
					E
					E
E	E	E	2–1	1–2	E
		E	1–1, 2–1	E	
0–2, 2–9	E	0–2, 1–3	E	E	
E	2–11	E	E	1–2	
E		E	E		
	1–1	E	2–1		
E		E	E	E	
	E	1–21	E	2–4	1–4, 2–5

IBI Metrics and Scores

Scott Run		Bullneck R.		Difficult 1		Difficult 2		Difficult 3		Difficult 4	
6/22 (.27)	2	7/18 (.38)	2	11/31 (.35)	2	15/30 (.50)	3	12/22 (.54)	3	9/16 (.56)	3
6/19 (.31)	2	6/15 (.40)	2	11/26 (.42)	3	13/25 (.52)	3	11/19 (.57)	3	9/16 (.56)	3
0/0 (00)	5	2/3 (.66)	2	0/5 (00)	5	2/5 (.40)	4	1/3 (.33)	4	0/1 (00)	5
4/6 (.66)	2	4/7 (.57)	3	1/11 (.09)	5	4/15 (.26)	4	4/12 (.33)	4	3/9 (.33)	4
0.66	4	0.57	3	0.36	2	0.60	3	0.41	3	0.77	4
2/10 (.20)	1	3/7 (.42)	3	7/11 (.63)	4	6/11 (.54)	3	5/9 (.55)	3	6/10 (.60)	3
2/11 (.18)	1	3/10 (.30)	2	4/17 (.23)	2	8/16 (.50)	3	5/12 (.41)	3	2/6 (.33)	2
2/9 (.22)	2	2/6 (.33)	2	6/12 (.50)	3	5/11 (.45)	3	6/10 (.60)	3	4/6 (.66)	4
2/7 (.28)	2	3/7 (.42)	3	5/8 (.62)	4	6/10 (.60)	4	4/8 (.50)	3	3/7 (.42)	3
1/2 (.50)	2	0/2 (00)	0	0/4 (00)	0	1/4 (.25)	2	1/2 (.50)	3	1/1 (1.0)	5
	23		22		30		32		32		36
Fair		Fair		Fair		Good		Good		Good	

Appendix II—Extended.

Species	IBI Class	Cabin J. 1	Cabin J. 2	Rock R. 1	Rock R. 2
Anguilla rostrata	N, O, C, T	1–2	2–1	E	E
Campostoma anomalum	N, BH, SM, M	1–1, 2–2	E	E	E
Clinostomus funduloides	N, MI, MS, M	E	0–12, 2–14	0–2, 1–1, 3–6	1–1, 4–3
Cyprinella analostana	N, MI, SM, M	E	E	E	E
Ericymba buccata	N, BI, MS, M	E	0–7, 1–5, 2–3	E	E
Exoglossum maxillingua	N, BI, MS, M	E	E	1–5, 2–8, 3–1	
Luxilus cornutus	N, MI, MS, M	E	0–1, 1–2, 2–4, 3–1	E	
Nocomis micropogon	N, BI, SM, M	E			
Notemigonus crysoleucas	N, O, V, T	E			
Notropis amoenus	N, MI, MS, I	E		E	
Notropis hudsonius	N, BO, B, I	E			
Notropis procne	N, BI, MS, M	1–5	0–3	E	
Notropis rubellus	N, MI, SM, I	E		E	
Pimephales notatus	NN, BO, SM, T	E	E	E	
Rhinichthys atratulus	N, BI, MS, T	1–19	0–88, 1–7, 2–9, 3–19	0–9, 1–7, 2–10, 3–1	0–234, 1–53, 2–58
Rhinichthys cataractae	N, BI, MS, M	2–1	0–1, 1–7	2–2	E
Semotilus atromaculatus	N, MI, SM, T	E	0–15, 1–2, 2–2, 3–1, 5–1	0–1, 2–2, 3–5, 4–1	0–10, 1–9
Semotilus corporalis	N, MI, SM, M	E			
Catostomus commersoni	N, BO, MS, M	0–1	1–1, 2–7, 3–2, 4–3, 5–1	0–1, 2–1, 3–3	0–5
Erimyzon oblongus	N, BO, MS, M	E	E	E	
Hypentelium nigricans	N, BI, MS, M	E	E	E	
Moxostoma erythrurum	NN, BI, MS, M	E			
Mosostoma macrolepidotum	N, BI, MS, M	E			
Ameiurus natalis	N, BI, SM, T		E	0–2	
Ameriurus nebulosus	N, BI, SM, T				
Noturus insignis	N, BI, SM, M	E	E	3–1	E
Salmo trutta	NN, MI, MS, M				
Salvelinus fontinalis	N, MI, MS, I				
Percopsis omiscomacus	N, BI, V, I	E	E	E	
Cottus girardi	N, BI, SM, M	E	E		
Lepomis auritus	N, MI, SM, M	1–1, 3–16	E	0–2	E
Lepomis cyanellus	N, MI, SM, M	E	E	0–1, 1–1	
Lepomis gibbosus	NN, MI, SM, T	E	E	E	
Lepomis macrochirus	NN, MI, SM, T	E	E	1–1	
Micropterus dolomieu	NN, P, SM, M	2–4	E		
Micropterus salmoides	NN, P, SM, M	E			
Etheostoma blennioides	NN, BI, MS, M	2–14			
Etheostoma flabellare	N, BI, SM, M	E	E	0–3, 1–3, 2–5	
Etheostoma olmstedi	N, BI, SM, M	E	0–10, 2–1	0–1, 1–1	E

IBI Metrics and Scores

Metric	Cabin J. 1	Score	Cabin J. 2	Score	Rock R. 1	Score	Rock R. 2	Score
Total Species Present/Expected	9/35 (.26)	2	10/26 (.38)	2	13/26 (.50)	3	4/12 (.33)	2
Native Species Present/Expected	7/28 (.25)	2	10/22 (.45)	3	11/24 (.45)	3	4/12 (.33)	2
Nonnative Species Present/Expected	2/7 (.28)	4	0/4 (00)	5	2/3 (.66)	2	0/0 (00)	5
Total Tolerant Species/ Total species	3/9 (.33)	4	3/10 (.30)	4	3/13 (.23)	4	2/4 (.50)	3
Percentage Species 2+ Age Classes Present	0.22	2	0.80	4	0.61	4	0.75	4
Mineral Substr. Simple Spawners Pr/Exp.	5/14 (.35)	2	7/10 (.70)	4	5/11 (.45)	3	3/5 (.60)	3
Substrate Manipulator Spawners Pr/Exp.	3/17 (.17)	1	2/14 (.14)	1	6/13 (.46)	4	1/6 (.16)	1
Benthic Insectivores Present/Expected	4/14 (.28)	2	5/12 (.41)	3	7/11 (.63)	4	1/5 (.20)	1
Midwater Insectivores Present/Expected	1/11 (.09)	1	2/8 (.25)	2	5/10 (.50)	3	2/4 (.50)	3
Benthic Omnivores Present/Expected	1/4 (.25)	2	1/3 (.33)	2	1/3 (.33)	2	1/1 (1.0)	5
Total IBI Score (of possible 50)		22		30		32		29
Habitat Rating	Fair		Fair		Good		Fair	

Appendix III

Supplemental sources of collection data and other information not published in the primary literature. Sources are on file with respective agencies and the author.

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